THE REDUCTION OF NOISE FROM TEXTILE MACHINERY

by

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SUMMARY

The purpose of this Interdisciplinary Higher Degree Scheme project was to investigate the incidence of high noise levels in Courtaulds' factories, and to advise on methods of reducing the problem.

A survey was made of noise levels in the factories. A study of existing research showed the effect the high noise levels are having on employees' hearing, and this leads to a maximum recommended noise level for the Courtaulds Group.

The importance of using hearing protection where unavoidable was discussed, together with its limitations. A feasibility study was performed to assess the value of audiometric measurement of employees' hearing. Two specific machines, the KMT Uptwister and the Horizontal Strander, were studied in depth to devise methods of noise control. Analysis of the sources of noise in each machine was followed by suggestions for the best practicable means of controlling the noise.

The effect of future legislation on the Courtaulds Group was investigated. By looking at events in other industries, the impact of civil claims for damages by employees suffering from hearing loss was predicted. Throughout the project, conclusions are drawn from experience gained in studying noise problems in the factory, and from discussions with managers, machine operators, engineers and union officials. The project finishes with recommendations for future Group policy on noise.

NOISE CONTROL MACHINERY TEXTILE INDUSTRY

To Ali,
and to my mother and father

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Introduction to the Project

Chapter 1

Introduction to the Project

A three year project was started in October 1975 to study the problem of high noise levels in Courtauld's factories. This thesis describes the work which was undertaken during the course of the project, and reports the conclusions which were reached and the resulting recommendations.

Like many other companies, particularly those in the textile industry, Courtaulds employ many workers in conditions of high noise. During the past fifteen years research has demonstrated the connection between excessive noise and hearing loss. The current attitude of society rightly deplores the fact that such conditions exist. This is reflected in legislation, both enacted and proposed. Workers, themselves, are becoming less tolerant of unpleasant and hazardous factory conditions, and noise is an increasingly significant factor.

The purpose of the project was to discover the exten~~d~~t of the noise problem and to investigate ways of gradually reducing it. This included a fundamental study of specific machines to find methods of reducing noise emission, with which the Mechanical Engineering Department of Aston University were able to assist. Throughout the project I was working very closely with engineers in the Engineering Development Department of Courtaulds at Coventry. Some of the Department's work already involved noise measurement and noise control. Noise analysis and control programmes were undertaken on two machines, the Uptwister which is a textile processing machine, and a Horizontal Strander, used in the manufacture of Steel tyre cord. In the case of the latter the project was a major step towards reducing the noise level in which more than 400 people work from 105 dB(A) to less than 90 dB(A).

The early part of the project was spent in performing noise surveys and in collecting noise level measurements. With the experience gained from the machine noise control programmes I travelled to several factories within the Group to advise on methods of noise control. It would have been impossible, in just three years, to make a major impact on reducing the total number of persons working in excessive noise environments by studying specific machines in depth. The emphasis therefore changed during the course of the project from a search for engineering solutions for specific machines, towards regarding the problems as one of management. If a system of guidance coupled with a facility for noise control advice were established, the long-term benefits would be greater.

The experience, which had already been gained in the course of the earliest part of the project, was supplemented on the later stages by talking with other people in the field of noise. Discussions were held with representatives of the Factory Inspectorate, the Health and Safety Executive and local authorities. The experience of other companies, both in the textile industry and in completely unrelated industries, was sought. In this way a picture was built up of the pressures on Courtaulds to reduce noise levels, which are likely to develop in the medium and long term.

By talking to those concerned with noise problems in the Group it was possible to establish how central advice could best be integrated into the company's management structure. Through discussions with the Safety and Medical Departments a Group Standard on Noise was developed. This it is hoped will have a mandatory as well as an advisory function. The non-engineering chapters of this thesis show how the Standard is a result of experience gained in earlier parts of the project. In addition, a study of the research into the effects of noise on hearing leads to recommendations for the choice of a target maximum permitted noise level in Courtaulds' factories. A discussion of hearing protection and audiometry concludes with recommendations for Group policy on audiometric monitoring of employees' hearing. All the recommendations are drawn together into the final chapter, where proposals for the formation of a specialist Noise Control Unit are also discussed.

This thesis does not include every noise problem which was investigated during the course of the project. Those which have been included are the major noise control projects, and typical examples of other aspects of the work. Some of the findings cannot be published due to commercial and employee relations sensitivity, notably the results of a questionnaire survey which asked for the number of employees at each of the Group sites exposed to 90 dB(A) or more. However, the following Chapters present a balanced account of the research and recommendations of the project.

2

Noise and the Courtaulds Group

Chapter 2

Noise and the Courtaulds Group

2.1 Introduction

Plant noise level surveys have been made at many sites in the Courtaulds Group during the past five years. Some have been as part of this research programme, some by other Engineering Development Department personnel, some by the Group Medical Department, and others by local management on the site. With a total of over 300 sites in the United Kingdom it was not possible or desirable to visit each site to repeat the measurements. Noise levels were surveyed in a wide range of factories, usually at the request of local management. The remainder of the data was obtained by searching all available information on noise levels in the Courtaulds Group.

2.2 The Structure of the Business

The interests of Courtaulds Limited can be divided into the following categories:-

1. Man-made fibre manufacture
2. Yarn production
3. Fabric manufacture

4. Garment production

5. Non-textile activities

The management structure of the company is not rigidly divided into these five areas. Many of the divisions are based on historical units.

During the middle and late 1950's many relatively small textile, and non-textile, firms were drawn into the Courtaulds Group. Many have kept their own identity, often with their own boards of directors responsible to the Main Board. This is particularly true in the fabric manufacture and garment production areas, known as the "downstream" end of the business. Exquisite Fabrics, Clutsom-Penn International, Meridian, Moygashel and Wolsey are familiar names, and it is on units such as these that the structure of the Company is built. The types of yarn used, and the processes through which the yarn is passed, are often very similar at factories in different companies. In many cases there is direct competition between two or more companies within the Courtaulds Group.

At the "upstream" end the fibre and yarn production is the responsibility of the divisions, such as Celon Division, Courtelle Division or Polyester Division, which are each associated with a single type of fibre. Similarly

Northern Spinning Division is almost entirely devoted to yarn production, although many types of fibre may be used.

The non-textile activities now form a very significant part of the Group's activities. They are organised very much according to the nature of the product. The manufacture of paint by the International Paint Company, the manufacture of packaging materials by British Cellophane Limited, and various projects involving plastics by National Plastics Limited are the chief non-textile activities. There are also factories manufacturing steel drums and steel tyre cord.

The main divisions within the Courtaulds Group are shown in Figure 1. The diagram indicates the position each textile division holds in the progression from raw material to completed garment. Some divisions, as already stated, cannot be easily categorised into a single function, but for convenience they have been included under their major function. It should also be noted that a large proportion of the fibre and yarn produced by Courtaulds is sold to Companies outside the Group who manufacture their own fabrics and garments, but are not fibre and yarn producers.

2.3 Man-Made Fibres

There are two fundamentally different starting

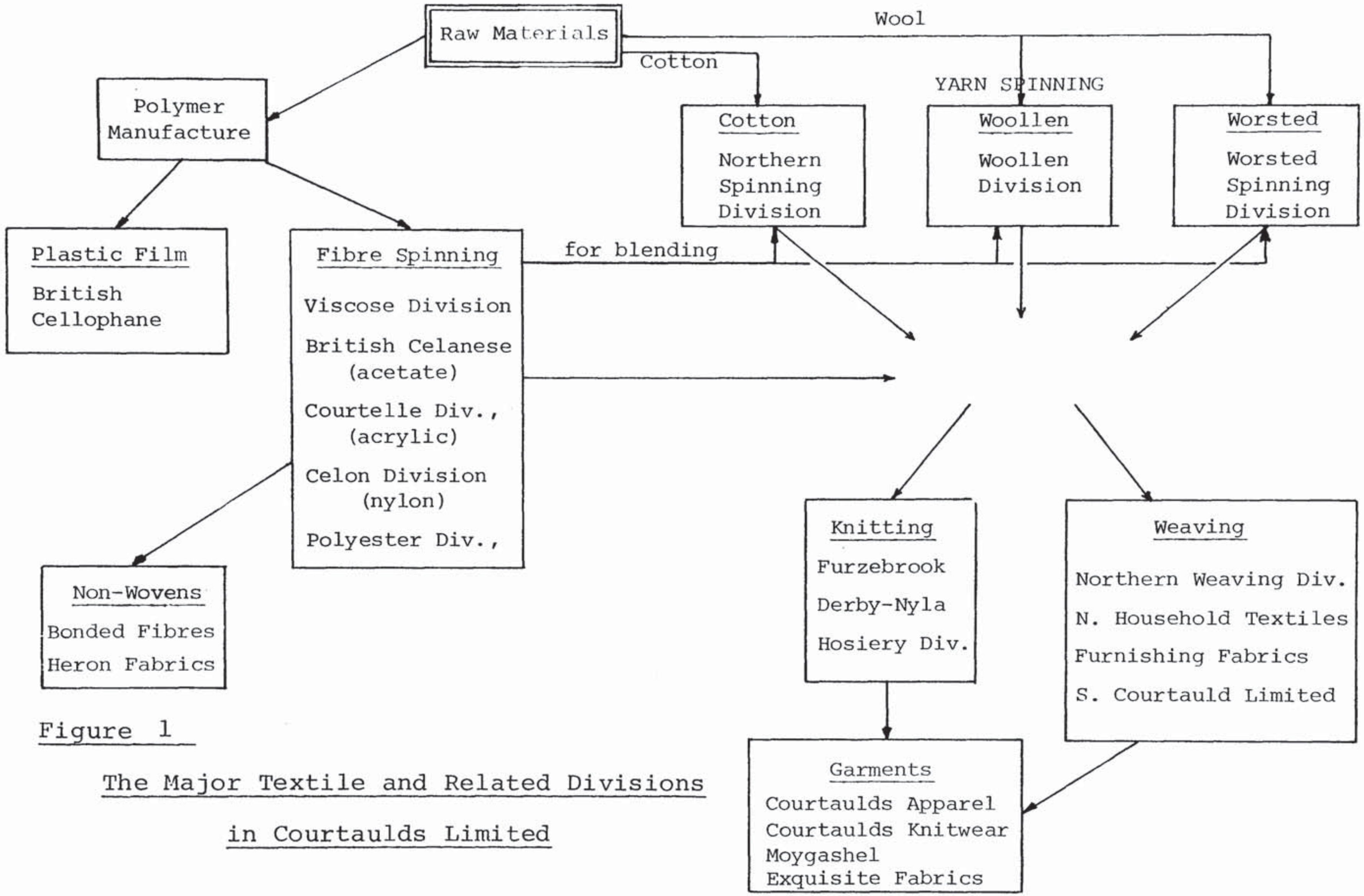


Figure 1

The Major Textile and Related Divisions
in Courtaulds Limited

materials for manufacturing man-made fibres, and they are the precursors of two classes of fibre which have very different properties. Wood pulp is the chief raw material in the manufacture of cellulosic fibres. Cellulose, in the form of wood, has a fibrous structure which is transformed into another type fibre more suitable for making into fabric. Synthetic fibres are made from either petroleum or coal. The fibres are generated by polymerisation followed by extrusion, resulting in continuous filaments.

Nylon is a polyamide manufactured by Courtaulds under the trade name of "Celon." It is produced at three large sites, at which the typical noise levels are as shown in Table 1. The nylon polymer is made in multi-storey chemical plants, where noise is caused by pumps and motors. The small cubic polymer chips are then melted and extruded through a large number of holes in the nylon spinning area. The nylon solidifies rapidly, and the many filaments are collected together and wound onto a package. The wind-up unit is the chief source of noise in this area, the level depending on the traverse rate of the feed onto the package as it rotates. Noise levels are very much higher for the first few minutes of a new package, during the operation known as the "lash up." Although the period is relatively short compared with that of a complete package formation, or doff, an operator is necessarily present. Each operator is responsible for a large number of take-up units and therefore spends a significant proportion of his time lashing-up.

In a subsequent process, known as drawtwisting, the spun fibre is drawn to around five times its original length in order to align the long polymer molecules in the direction of the fibre and thereby improve its strength. At the same time the fibre is twisted so that the individual filaments are held closely together. The noise is generated in drawtwist machines by the rollers which stretch the fibre, and by the rapidly rotating take-up spindle which introduces the twist. The manufacture of polyester, marketed by Courtaulds under the trade name "Lirelle," is fundamentally the same as nylon, although the physical properties are different.

The production of acrylic fibre differs from nylon and polyester in several ways. "Courtelle" is Courtaulds' trade name for acrylic fibre. Instead of being melt-spun the polymer (polyacrylonitrile) is dissolved in a solvent, filtered and pumped as a liquid through a spinnerette and into a coagulating bath. A spinnerette is a plate containing many thousand small holes, typical diameter 63 microns and the filaments thus formed are collected together into a tow. The tow is washed to remove the excess solvent, sometimes dyed and dried.

The spinning deck at a Courtelle Plant can have ten coagulating baths. The process of wet spinning is comparatively quiet, and the extraction equipment for removing fumes accounts for the noise shown in Table 2 Also recorded are typical noise levels in the filtration area, (where noise is caused by pumps), in the washing area and around the dryers. The dryers are large rotating drums which carry the tow inside a long oven, through which warm air is blown by several large fans.

Two types of fibre manufactured from cellulose are acetate and viscose. Rayon is a viscose fibre, and the production of the fibre consists of regenerating the cellulose from a solution of treated wood pulp in sodium hydroxide. The solution is extruded into a coagulating bath of sulphuric acid through tiny jets, causing the regeneration of the cellulose. Noise levels in the viscose production process are shown in Table 3.

Acetate fibres, although made from wood pulp, are chemically very different from cellulose. Before spinning the wood pulp is acetylated to form cellulose acetate, which is then dissolved in acetone. Acetate fibres are dry-spun, with the cellulose acetate solution pumped through fine jets. The acetone rapidly evaporates in a warm air stream leaving the solid acetate. The fibre is slightly stretched as it is wound onto bobbins or cheeses.

During the winding process, the many filaments in each fibre are combined together, either by inserting twist or by passing the fibre through an interlacing jet, which randomly intermingles the filaments. The latter method can operate at much higher speeds.

Triacetate fibre is produced in the same way as acetate fibre, although it is chemically slightly different. The noise levels shown in Table 4 are typical of acetate and triacetate production. The dry spinning process itself is quiet, and the high noise levels are again entirely due to the take-up winders. Cigarette filters are made of acetate fibres. Instead of fibres being produced with a few hundred filaments, tens of thousands of filaments are combined to form a tow which is cut to length for the cigarette filters.

2.4 Spinning to Produce Yarn

Spinning is the process by which short lengths of fibre, known as staple fibre, are twisted together and drawn-out to produce a fibre of indefinite length, known as yarn. The staple fibres may be natural, such as cotton or wool, or man-made filaments cut to staple lengths. The individual fibres cling together as they overlap along their length, and thus produce a yarn of sufficient tensile strength to be converted into fabric.

There are three types of spinning process named according to the type of yarn traditionally formed by each. They are cotton, woollen and worsted spinning. Wool is either spun by the woollen spinning method, or by the worsted spinning method depending on the type of fabric required. Man-made fibres are spun by any of the methods, depending on the properties of the fibre and the type of fabric required. They are spun either alone or mixed with wool or cotton as appropriate.

The fundamental operations of spinning are similar in the three types. They are carding, drawing, twisting and winding. The carding process disentangles the fibres and thoroughly mixes the different fibres if a mixed yarn is required. The fibres are teased apart by two sets of wire bristles in the carding machine. The product is a thick rope of fibres, known as a sliver, which is coiled into a rotating can.

The worsted spinning process differs from the woollen spinning in that the wool for worsted yarn is combed after carding. The short fibres are removed during the combing to leave only the longer wool fibres in an improved parallel order. Cotton is sometimes combed if the fibres are sufficiently long and if a finer lustrous yarn is required.

The slivers produced by carding and combing are drawn out to many times their original length to reduce the diameter. The drawframe consists of many pairs of nip rollers (rotating rollers which grip the sliver between them.) Each successive pair is rotating faster than the previous pair. Differences in uniformity in the diameter of the sliver are reduced by doubling. Several slivers are combined after drawing, and then redrawn. The parallel order of the fibres is also improved during the drawing process. The result of the drawing process is a much finer rope, known as a roving, which is wound onto bobbins.

The spinning process is a combination of three operations. The roving is drawn still further to form very fine strands of fibre which are then twisted. The commonest form of spinning uses a ring carrying a traveller through which the yarn passess before being wound onto a high speed rotating bobbin in the centre of the ring. The traveller passess around the ring so that twist is introduced, but it does not rotate at the same rate as the bobbin. The winding and twisting operations are therefore combined.

Ring spinning produces yarn on cylindrical bobbins. In order to be suitable for fabric manufacture the yarn has often to be rewound onto cones. There is usually a final winding stage to the spinning process, therefore. Further stages are sometimes introduced before the final

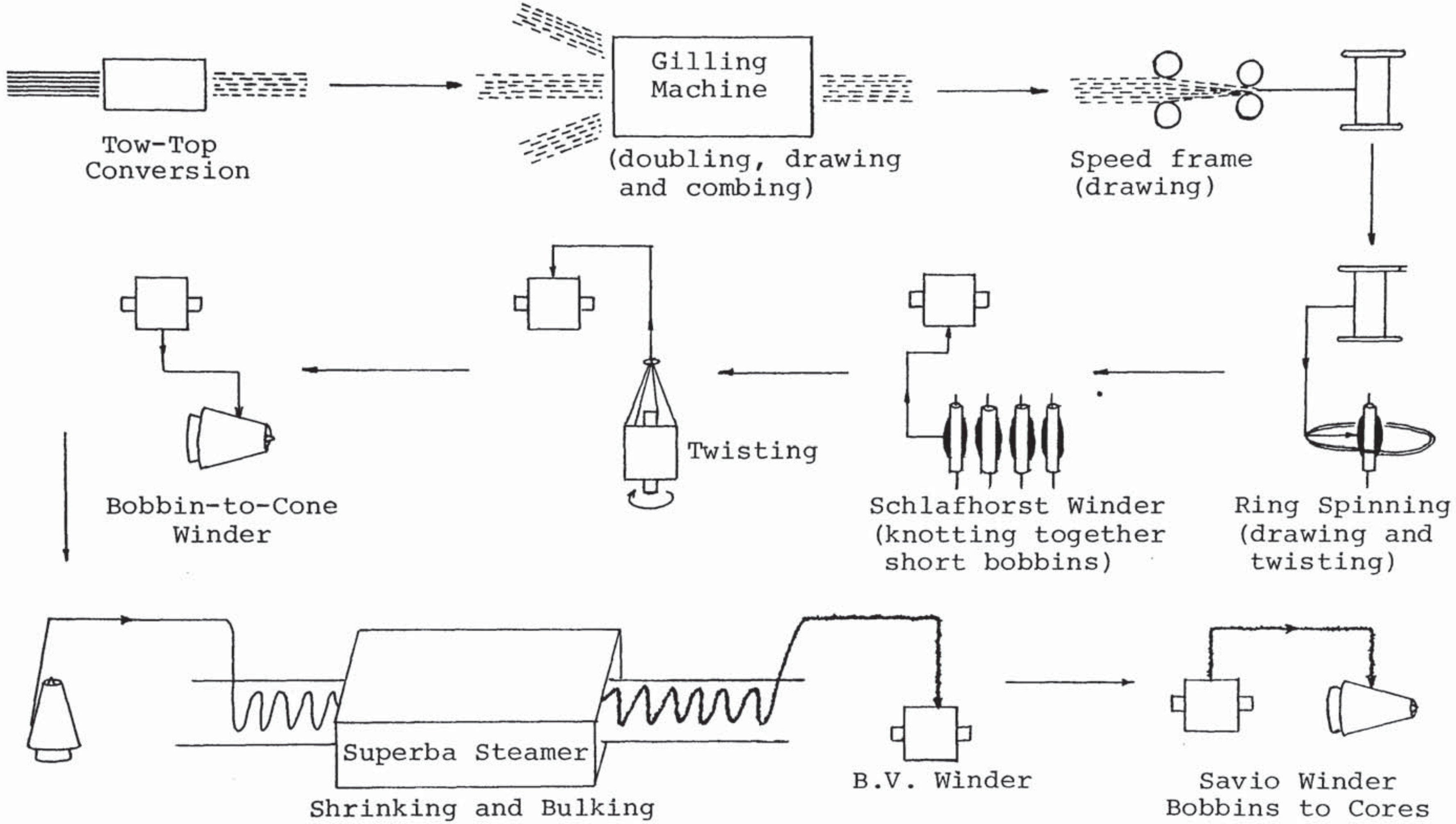


Figure 2

The Worsted Spinning Process

winding takes place. The yarn can be dyed, or steamed to cause shrinkage, or occasionally redoubled to create extra uniformity or blends.

An example of the number of stages associated with the spinning process is shown in Figure 2. It is a diagram of the passage of fibre through Westcroft Mill in Bradford. The mill processes acrylic fibre in the worsted spinning tradition. The continuous filaments are stretch-broken into staple lengths in the process known as tow-to-top conversion.

Typical noise levels in cotton spinning, worsted spinning and woollen spinning are shown in Tables 5,6 and 7 respectively.

2.5 Weaving

The two important fundamental processes for manufacturing fabric from yarn are, of course, weaving and knitting. The difference in the structure of fabrics produced by the two quite different processes are evident from the diagrams in Figure 3. The two methods of knitting are discussed in the next section. The properties of woven and knitted fabrics are also different, for example the looped nature of knitted fabric enables it to be stretched and released to return to its original

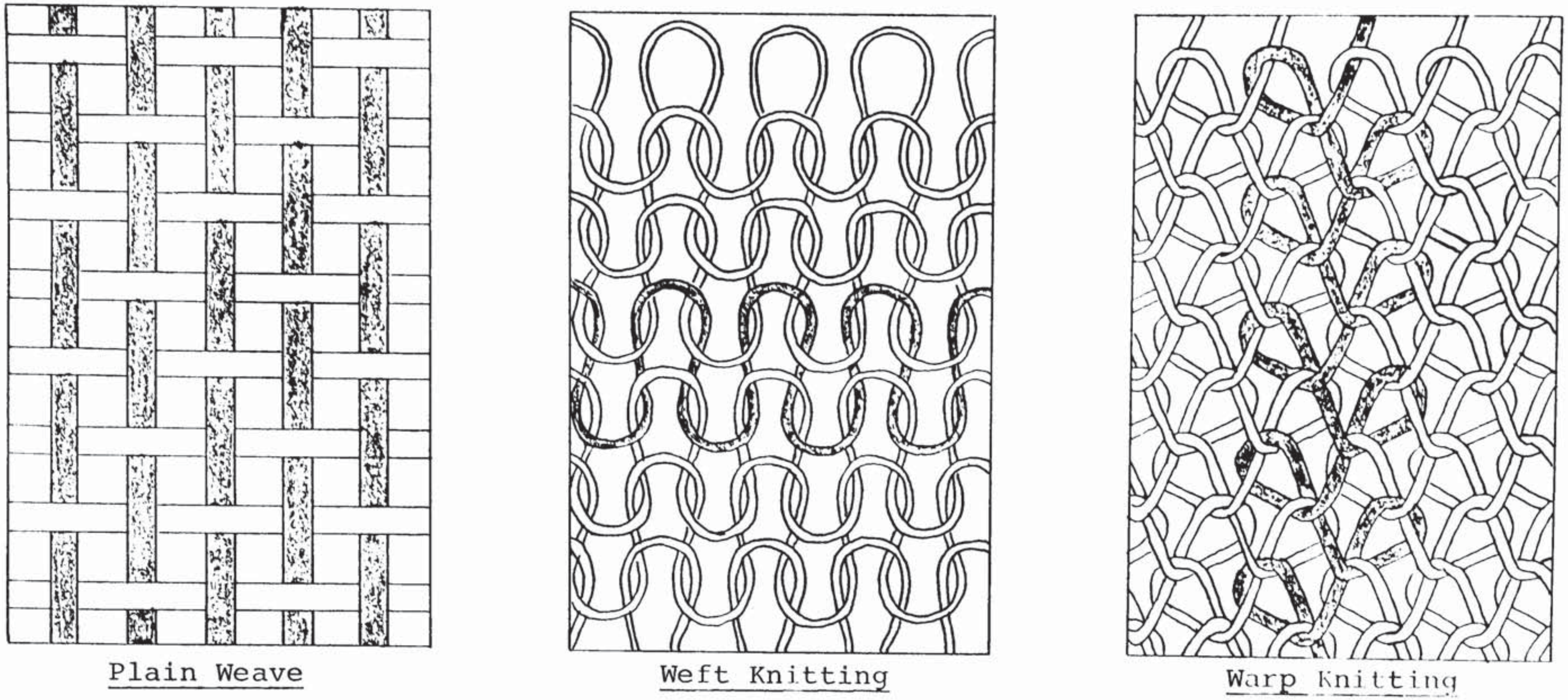


Figure 3

Structure of Woven and Knitted Fabrics

position.

The weaving diagram in Figure 3 is a plain weave, in which a weft, shown in white, is passed back and forth between alternate warps. For each insertion of the weft the two sets of warps are held apart while the weft is passed across. The positions of the two sets of warps are then reversed and the weft is passed again. Intricate patterns are produced by programming the loom to raise and lower each warp separately, instead of alternate warps in each direction as in the plain weave described above. There are three processes carried out by the loom; passing the weft, changing the position of the warps (shedding) and beating-up, in which the newly formed weft is pushed up to lie next to the previous weft. All these processes involve sudden movements of relatively massive parts of the machine at cycles of up to 250 cycles per minute. The level of noise generated is therefore high, and is of a chattering nature. There are usually between twenty and two hundred looms in one room, which means the overall noise in the room appears to be continuous rather than impulsive.

In traditional looms the weft is carried through the shed, the two sets of warps, by a shuttle, which carries the bobbin of yarn with it. New types of loom are being introduced which do not use a shuttle. In the

Sulzer loom an end of the weft is carried across by a gripper, which weighs very much less than the traditional shuttle. Courtaulds have installed some high speed looms which insert the weft by the force of an air jet or water jet. The modern types of loom cut each weft in order to avoid carrying the bobbin, and therefore the weft does not run continuously back and forth through the whole length of the fabric. Water jet looms and the Sulzer looms produce considerably lower levels of noise than shuttle looms, although the noise levels are still high. Air jet looms are noisier due to the air turbulance of the jet.

The principles of weaving are the same for all types of yarn, although the speed of the process depends on the strength of the filaments and their liability to be damaged. Filament weaving, using continuous fibres, operates at the highest speed and therefore generates the highest noise levels. Typical noise levels in the weaving industry are shown in Table 7 and Table 8.

2.6 Knitting

A knitted fabric is a series of interlocking loops produced by needles which are designed to hook new yarn and draw it back through the already formed loops. The movement of a knitting machine is a short to and fro movement by an array of needles. The process is necessarily slow, and this combined with the small movements in knitting machines means noise levels are relatively low.

There are two fundamentally different methods of knitting, and the structure of the fabrics are shown in Figure 3. If the fabric is produced from a single yarn which runs horizontally the process is weft knitting. If one or more threads are supplied to each needle, and the threads run lengthwise through the fabric, the process is warp knitting. The structures shown in Figure 3 are the plain, simple forms. There are many variations to these stitches, each producing a different effect in the fabric. For example purl knitting produces ridges, and the use of the rib stitch results in a bulkier fabric known as double jersey. Warp knitted locknit stitch resists laddering.

The warp knitting machines run at higher speeds than the weft knitting machines, and therefore produce higher noise levels, as shown in Table 9. There are three types of weft knitting machines. Circular knitting machines produce a tubular fabric of constant diameter which is normally cut for sale as a flat fabric. The garments made from circular knitted fabric are therefore usually cut to shape. Straight bed knitting machines, on the other hand, are able to knit fabric to almost any shape. The width of the fabric can be changed, and therefore parts of garments are produced directly without the need to cut the fabric before making-up the garment. This is known as fully-fashioned knitwear. The third type is the flat bed machine, which until recently had the same restrictions as circular knitting machines. They are very versatile in the patterns and colours which they can create.

2.7 Hosiery

Hosiery wear is knitted fabric produced from low decitex (very fine) yarn, usually nylon. The more common seam-free garments are produced on small diameter circular knitting machines, and the elasticity of the fabric enables it to adjust to the natural contours of the leg. By transferring the fabric from one machine to another the three parts of hosiery garments, the top, the plain section of the leg, and the foot can be produced automatically.

Fully fashioned stockings, which are shaped to the leg and have a seam, are produced on flat bed knitting machines. (See Table 10).

2.8 Non-Woven Fabrics

The slow production rate, and therefore high cost, of producing fabric by knitting or weaving has led to the development of other types of fabric, commonly known as "non-wovens." There are several ways in which the fibres are held together in the fabric. Bonded Fibres Limited, part of the Courtaulds Group, make fabric where the fibrous web is bonded together by adhesive. Heron Fabrics produce a stitch-bonded fabric, in which a web of viscose fibres are stitched with a conventional yarn. The stitch-bonded fabric, produced principally on Arachne machines, has a 65% proportion of viscose fibre, and can be produced at 5 times the rate of woven fabric on a loom. The quality of the fabric is not as good, but stitch-bonded fabrics are commonly used for curtaining material and similar applications.

The viscose fibres are carded, in the same way as in the production of yarn, but the thin web is not gathered together to form a sliver. Instead the webs are laid on top of each other with successive layers perpendicular to each other. The fibres orientated in the carding process are therefore also laid perpendicular to increase the strength across the fabric. The viscose mat is then bonded. The noise levels normally associated with each stage are shown in Table 9.

2.9 Stretch Fabrics

Clutsom-Penn International Limited specialise in manufacturing stretch garments. The fabrics are produced by conventional methods of knitting and weaving, but using a proportion of elastomeric yarn to provide the stretch. One site of Clutsom-Penn specialised in weaving narrow fabrics for bra straps amongst other applications. The noise levels are similar to those for the similar processes in other parts of the Group. However, for many applications, where the elastomeric fibre makes contact with the skin, it has to be covered. The covering process involves passing the elastomeric fibre through the centre of a rotating spindle which winds a fine thread of nylon or cotton around Lycra. The throughput is very slow, but high noise levels are generated by the rotating bobbins.

2.10 Non-Textile Processes

Factories in the Courtaulds Group not producing textiles have some of the highest noise levels. The principal examples are shown in Table 11. The International Paint Company, the largest paint manufacturers in the world, have a large number of ball mills which grind pigment in rotating drums containing steel or porcelain balls. Drums Limited manufacture containers from sheet steel. Steel Cords Limited produce steel tyre cord for bracing vehicle tyres. Filaments of brass coated steel are stranded, or twisted together, on machines which produce very high noise levels.

Cellophane is produced by British Cellophane Limited from wood pulp in the same way as viscose fibre. The casting process equivalent to the extrusion of viscose fibre, generates noise principally in the drive transmission which transports the cellophane sheet through baths and driers. High speed slitting of the cellophane to produce rolls of the required width is sometimes a source of high noise levels. Glass fibre is manufactured by Marglass, using parallel techniques to textile fibre production, and the glass fibre is even woven into glass fibre matting. National Plastics Limited have injection moulding machines and presses for manufacturing plastic items. The highest noise levels in the industry are to be found near the granulators which reduce the waste plastic material.

This completes the survey of typical noise levels found in Courtaulds factories.

Table 1

Noise Levels in Courtaulds
Man-made Fibres
Nylon Manufacture

Polymer Plant		85-92 dB(A)
Spinning take-up		
traverse rate of	450 c.p.m.	87 dB(A)
	750 c.p.m.	90 dB(A)
lash-on		98 dB(A)
Drawtwisting		
running speed of	800 m per minute	93 dB(A)
	1000 m per minute	96 dB(A)
	1500 m per minute	98 dB(A)

Table 2

Noise Levels in Courtaulds

Man-made Fibres

Acrylic Fibre Manufacture

Polymer filtration	86 dB(A)
Spinning	88 dB(A)
Tow washing	83 dB(A)
Tow dryers	85 dB(A)

Table 3

Noise Levels in Courtaulds Man-Made Fibres

Viscose

Spinning	95 dB(A)
Acid circulation	90 dB(A)
Shredders	86 dB(A)
Steep floor	81 dB(A)
Granulators	91 dB(A)

Table 4

Noise Levels in Courtaulds
Man-made Fibres
Acetate and Triacetate Manufacture

Spinning platform		84-86 dB(A)
Spinning take-up		
spin-twist	(220m/min)	88 dB(A)
air interlaced	(440m/min)	92 dB(A)
air interlaced	(510m/min)	94 dB(A)
lacing up		97 dB(A)
Cigarette tow (Dicel)		
spinning		84 dB(A)
crimping		89-93 dB(A)
Processing acetate and triacetate		
coning		93 dB(A)
doubling		95 dB(A)
crimping		107 dB(A)
downtwisting		98 dB(A)
uptwisting		96 dB(A)
air texturising		109 dB(A)

Table 5

Noise Levels in Courtaulds

Cotton Spinning

Carding			86 dB(A)
Combing			85 dB(A)
Doubling			101 dB(A)
Drawing	Speedframe	(Platts)	90 dB(A)
	Globe	(Platts)	91 dB(A)
	Mercury	(Platts)	90 dB(A)
Ring Spinning			95 dB(A)
Break Spinning			99 dB(A)
Winding	Schlafhorst		91 dB(A)
	Arunco		90 dB(A)
	Conematic		91 dB(A)
	Savio		91 dB(A)
	Holts		94 dB(A)

Table 6

Noise Levels in Courtaulds

Worsted Spinning Process

Tow-to-top converters	89-93 dB(A)
Gilling machines	95 dB(A)
Speedframe (Tower)	89 dB(A)
Ring spinning (Platt)	93 dB(A)
Schlafhorst winder	90 dB(A)
Twisting (Platt-Saco-Lowell)	89 dB(A)
Bobbin-to-cone winder (Leesona)	82 dB(A)
Superba steamers	84 dB(A)
B.V. winders	93 dB(A)
Savio winders	93 dB(A)

Table 7

Noise Levels in Courtaulds

Woollen Spinning and Weaving Processes

Carding	-	Haigh	84 dB(A)
	-	Cliff	79 dB(A)
Mule Spinning	-	Charlesworth	92 dB(A)
Ring Spinning	-	Rieter	91 dB(A)
	-	Platts	90 dB(A)
Winding	-	Mettler	87 dB(A)
	-	Holts	92 dB(A)
	-	Roto coners	90 dB(A)
	-	Arunco	87 dB(A)
Weaving Looms	-	Dobcross	100-104 dB(A)
	-	Sulzer	98 dB(A)
	-	Northrop	100 dB(A)
	-	Hattersley	106 dB(A)
Finishing			82 dB(A)
Raising			88 dB(A)

Table 8

Noise Levels in Courtaulds

Cotton Weaving System

Weaving looms	- Sulzer	91-94 dB(A)
	- Ruti	100 dB(A)
	- Northrop	100 dB(A)
	- Northrop Jacquard	104 dB(A)
	- Saurer	101 dB(A)

Filament Weaving System

(Samuel Courtauld Limited)

Weaving looms	- Saurer	105 dB(A)
	- Draper/Luti	104 dB(A)
	- Kovo waterjet	94 dB(A)
	- Nissan water jet	92 dB(A)
	- Kovo airjet	100-105 dB(A)

Table 9

Noise Levels in Courtaulds

Knitting Process

Warp knitting		91 dB(A)
Circular knitting	- Kirkland	81 dB(A)
	- Terrot	79 dB(A)
	- Camber	80 dB(A)
	- Witt-Mallor-Bromley	79 dB(A)
Flat-bed knitting	(knitwear garments)	84-88 dB(A)

Stitch-bonded Fabrics

Carding	88 dB(A)
Cross folding	90 dB(A)
Arachne stitch-bonding machine	93 dB(A)

Table 10

Noise Levels in Courtaulds

Hosiery

Fully fashioned knitting	91 dB(A)
Seam-free (circular) knitting	90 dB(A)

Stretch Fabrics

Narrow fabric weaving		101 dB(A)
Knitting	warp	85 dB(A)
	weft	83 dB(A)
Elastic yarn covering		105 dB(A)

Table 11

Noise Levels in Courtaulds

Non-textile Processes

Paint Manufacture

Ball mills	- steel balls	97 dB(A)
	- porcelain balls	89 dB(A)

Cellophane

Casting cellophane sheet	91 dB(A)
Slitting and winding	91 dB(A) peaking to 96 dB(A)

Glass Fibre

Extrusion	85 dB(A)
Winding	94 dB(A)
Weaving	98 dB(A)

Table 11
(Cont.'d.)

Noise Levels in Courtaulds

Non-textile Processes (continued)

Plastics

Moulding	87 dB(A)
Press-shop	95 dB(A)
Waste granulator	103 dB(A)

Steel Drum Manufacture

Press-shop	102 dB(A)
Flanging	100 dB(A)
Welding	99 dB(A)
Printing department	101 dB(A)

Steel Tyre Cords

Stranding (twisting)	105 dB(A)

3

Hearing Loss and Limiting Noise Exposure

Chapter 3

Hearing Loss and Limiting Noise Exposure

3.1 Introduction

It has long been realised that prolonged exposure to high noise levels is one way in which hearing loss can occur. The disability is not known as deafness since the hearing is rarely lost altogether. However the lowest sound level detectable by the ear rises, and the ear is proportionately less sensitive to sound levels above the threshold. The result can be very unpleasant for the sufferer, particularly since the hearing loss does not occur equally at all audible frequencies. There is a disproportionate hearing loss at the upper frequencies of the range commonly used in speech, which are therefore drowned by the lower frequencies. In severe cases then, understanding of speech can be affected, and even become impossible.

An understanding of the quantitative effect of noise on hearing has been advanced considerably in recent years, particularly by the work of Burns and Robinson.[1] The risk to hearing by working in high noise level areas is widely known. Most people concerned with industry are aware that the risk increases greatly with the level of sound intensity. The duration of exposure to the noise is now known to be an equally important factor. The first step in eliminating the hazard as far as possible is to determine the level of noise which is acceptable for a given exposure duration. This is then a target for engineers to design towards, for managers to plan for, and for unions to press for. Meeting the standard will require education, persuasion and coercion, and it must be remembered that noise levels cannot be reduced immediately without serious damage to industry. In the meantime, the maximum acceptable noise level will determine in which areas hearing protection is required. The following shows how a maximum noise level standard is obtained, and the figure it should be in Courtaulds.

3.2 The Mechanism of Hearing

The hearing sensation is the result of a complex process which converts audible sounds of varying amplitude and frequency into neurological impulses which the brain can interpret as speech, music and other sounds. There are still many parts of the process which are not fully understood, particularly the central functions taking place within the brain. The peripheral functions, performed by the ear, combine to convert the incident air pressure oscillations into nerve impulses, which are transfered to the brain for interpretation. This area has been the subject of much investigation in recent years, and although much has still to be explained, some light has been thrown on the effect of excessive noise on hearing.

A diagramatic structure of the ear is shown in Figure 4. The air pressure oscillations enter the external auditory meatus, or ear canal, and couple with the tympanic membrane, or ear drum. The vibrations excited in the tympanic membrane are related in amplitude and frequency to the incident air oscillations, and the amplitude of the vibrations is proportional to their magnitude. The tympanic membrane normally seals the external auditory meatus, but the vibrations are transfered through the membrane to the middle ear. The vibrations are transfered to a coupled system of three tiny bones, the auditory ossicles. The first ossicle, the malleus, is coupled to the tympanic membrane. This drives the second ossicle, the incus, which in turn drives the third, the stapes, which causes oscillations to take place in the fluid contained in the inner ear.

The purpose of the middle ear is to amplify the pressure exerted on the tympanic membrane approximately thirty times, and also to provide a degree of protection from excessive noise to the inner ear. The middle ear is air-filled, with a channel to the nose, the Eustacian tube, equalising pressure on either side of the tympanic membrane.

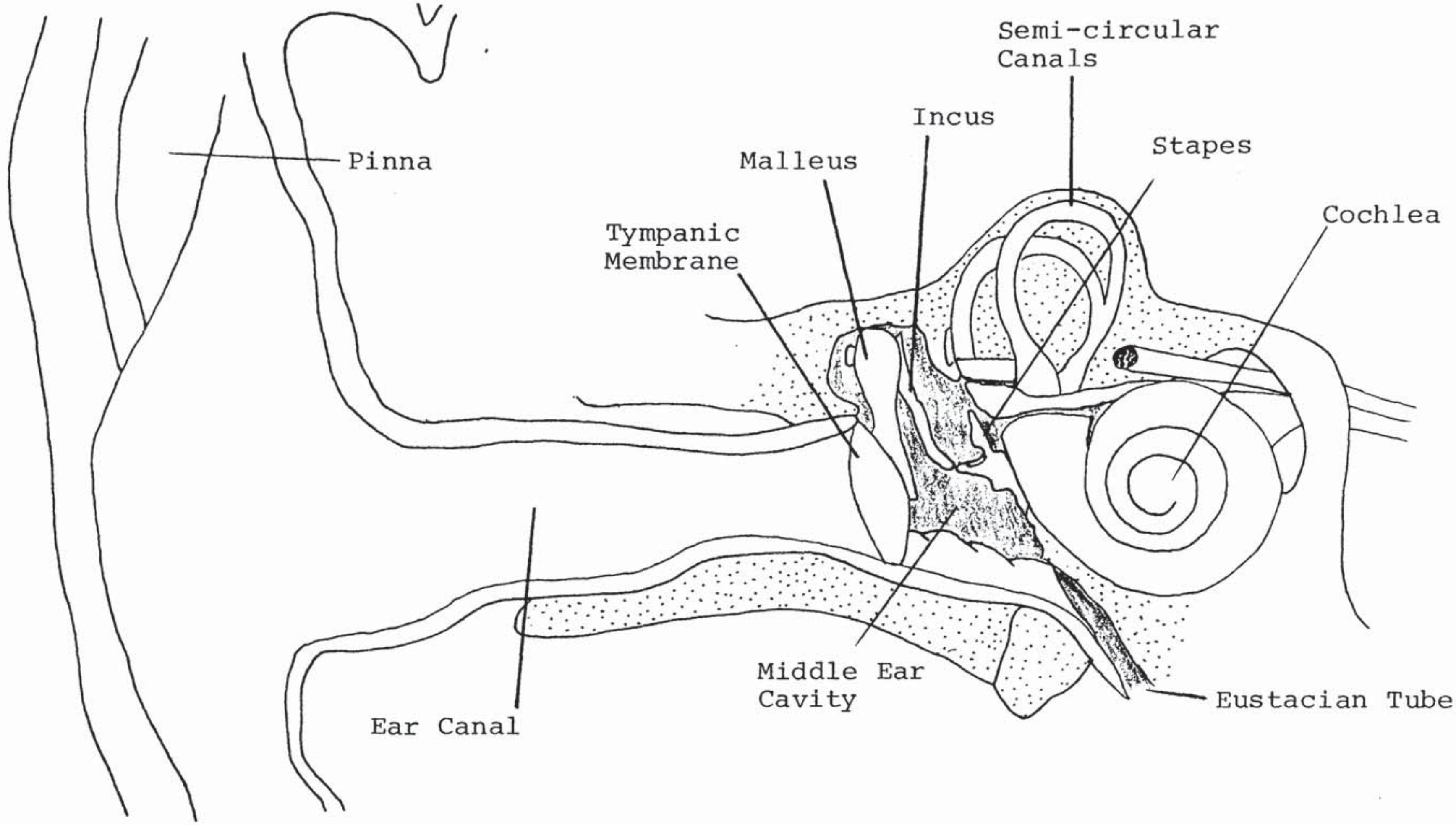


Figure 4

Structure of the Ear

The inner ear is embedded deep inside the temporal bone of the skull. The semi-circular canals are organs which assist with balance, and the final stage of the hearing mechanism of the ear is another canal known as the cochlea. The cochlea is coiled in a conical shape, like a snail's shell. It is partitioned longitudinally with fluid on either side of the partition. At the lower, broader end the cochlea is sealed by the oval window on one side of the partition, and by the round window on the other side. The vibrating stapes causes the fluid on one side of the partition to oscillate via the oval window. This in turn causes movement of the partition, in the other fluid and in the round window which provides elasticity to the system.

The partition is a very complex structure with a number of important properties. Firstly it has elasticity, and a graded mass and stiffness along its length, with the result that resonance will occur with vibrations of a wide frequency spectrum at different longitudinal positions. Secondly, it contains the organ of Corti which extends the length of the partition. The organ of Corti is composed of cells with many hairs which project into fluid contained inside the partition. The cells are also the end-points of the nerves which carry the signals to the brain.

When the partition is excited by a vibration transmitted through the middle ear to the fluid in the cochlea, the lower, broader end of the partition, having greatest stiffness and least mass, will deflect and start a travelling wave progressing longitudinally along the partition towards the apex of the cochlea. Due to the different resonances the wave reaches a maximum amplitude at a position along the partition which is entirely dependant on its frequency. The travelling wave is then extinguished and travels no further. In this way the partition acts as a frequency analyser.

Movement of the partition causes bending of the hair cells which in turn is thought to cause variation in the electrical resistance of the cells which support the hairs. The chemical potentials within nerve cells actively amplify the minute movements of the bending hairs into nerve impulses of considerably greater energy. A threshold level of excitation exists for any nerve cell, and within one frequency responsive area there will be a number of cells with differing thresholds. A low level signal may only trigger one cell whereas a higher level signal will trigger many more. The sensation of sound intensity is thus transmitted to the brain as a variation in the number of nerve cells activated at a certain position. The information describing the position of the hair cell in the organ of Corti must also be known to the brain in order to distinguish frequency.

The above description of the mechanism of hearing is merely a sketch of the principal structures and functions of the ear. Although our knowledge of the mechanism of hearing is far from complete, studies by Engström, Ades and Bredberg[2] and by Davis and Silverman[3] have produced much more detailed accounts than has been possible here.

3.3 The Effect of Excessive Noise on Hearing

Very little is understood of the way in which hearing loss occurs. There are three fundamental causes of hearing loss:-

1. Disease or infection
2. Old age
3. Excessive noise

Disease and infection can strike the ear in any part. For example, the common cold can reach the middle ear through the Eustacian tube and cause fluid to collect in the cavity. If the Eustacian tube becomes blocked the tympanic membrane may rupture resulting in discharge from the ear. Other diseases can affect the cochlea. Deafness can also result from tumours in the auditory nerve or cerebral thrombosis in the region of the brain concerned with hearing.

Hearing loss, particularly at high frequencies, is known to occur in all cases to a greater or lesser extent with advancing age. The condition is termed presbycusis and the change takes place in the cochlea and auditory nerve. Degeneration of the hair cells and associated nerve fibres occurs, but the cause is no better understood than the decline of other functions of the body with age.

Defects of the cochlea and auditory nerve result in what is called sensorineural deafness. The effect of excessive noise falls into this category. People who are regularly exposed to high noise levels find after a considerable time has elapsed they no longer hear as well as they could. Initially they will just notice a temporary loss of hearing which recovers during the course of an evening away from the noise. They may also notice ringing in the ears, or tinnitus. Eventually they will find that the temporary hearing loss becomes debilitatingly severe, and furthermore their hearing never completely recovers when the exposure to noise ceases.

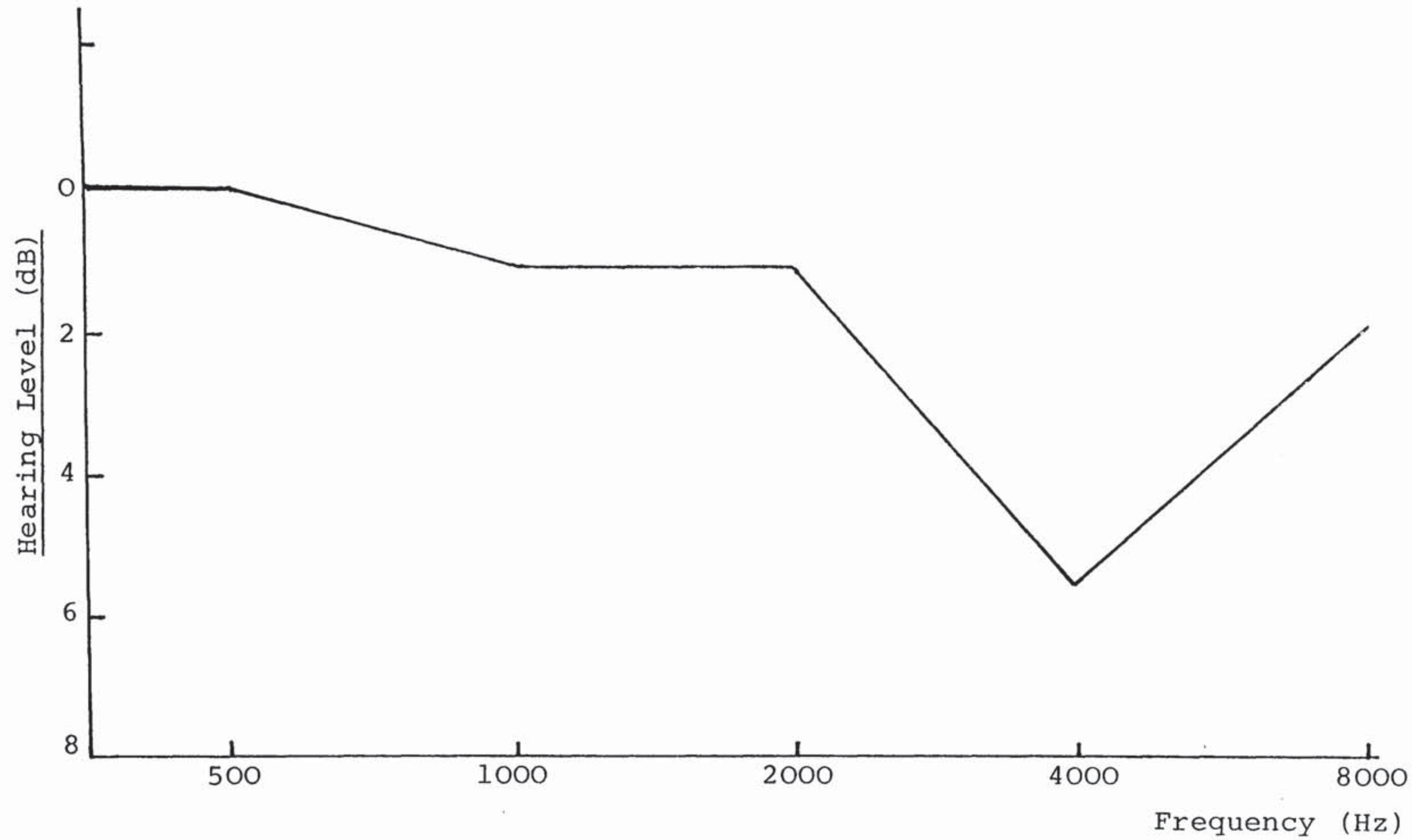
The hearing threshold of these individuals has risen, and their ears are correspondingly less sensitive to sounds above the threshold. This is known as threshold shift and many be either temporary (TTS) or permanent (PTS). As with presbycusis there is a withering of the hair cells and other parts of the organ of Corti. PTS is irreversible and cumulative, which suggests that as the hair cells are destroyed they never recover, and that the sensitivities of the hearing depends on the number of detecting hair cells. Obviously, exposure to extreme noise such as an explosion can also cause damage to the tympanic membrane and the ossicles of the middle ear, but we are concerned with the insidious loss in hearing which is caused by prolonged exposure to noise.

The degree of threshold shift can be measured using an audiometer. The function and operation of an audiometer are described in Chapter 5, but for the moment it is sufficient to state that an audiometer produces a trace of the hearing threshold of the ear under test as it varies with frequency, usually in the range 500 Hz to 6 kHz. The scale, in decibels, is the measure of the shift in threshold relative to a zero which corresponds to the normal threshold at each frequency of a young adult. A positive threshold shift of, say, 40 dB at 1 kHz implies a hearing loss with the sensitivity of hearing reduced by 40 dB at that frequency. A negative threshold shift implies a better than normal hearing sensitivity at that particular frequency.

Noise induced hearing loss is characterised by a marked hearing loss around the 4 kHz region. The reason is not known, although it seems clear that the ear as a whole is particularly sensitive in the region 3 kHz to 6 kHz. A typical audiogram for hearing loss due to noise exposure is shown in Figure 5. Presbycusis does not have the characteristic dip at 4 kHz and therefore the feature is useful in diagnosing noise induced hearing loss. If a quantitative measure of the degree of hearing loss due to noise is required, however, allowance must be made for the contribution of presbycusis to the overall hearing loss.

3.4 The Significance of Noise Intensity and Duration

Hearing loss is related to the intensity of the sound to which the ear is exposed, and to the duration of that exposure. For a constant duration, a particular ear will suffer a greater permanent threshold shift the greater the noise intensity. Similarly, for a constant noise level the PTS will increase with the duration of the exposure. This holds true for comparisons using a single ear. However the sensitivity to noise induced hearing loss varies from person to person quite dramatically. There is at present no method of determining the sensitivity to noise of each person in advance of the



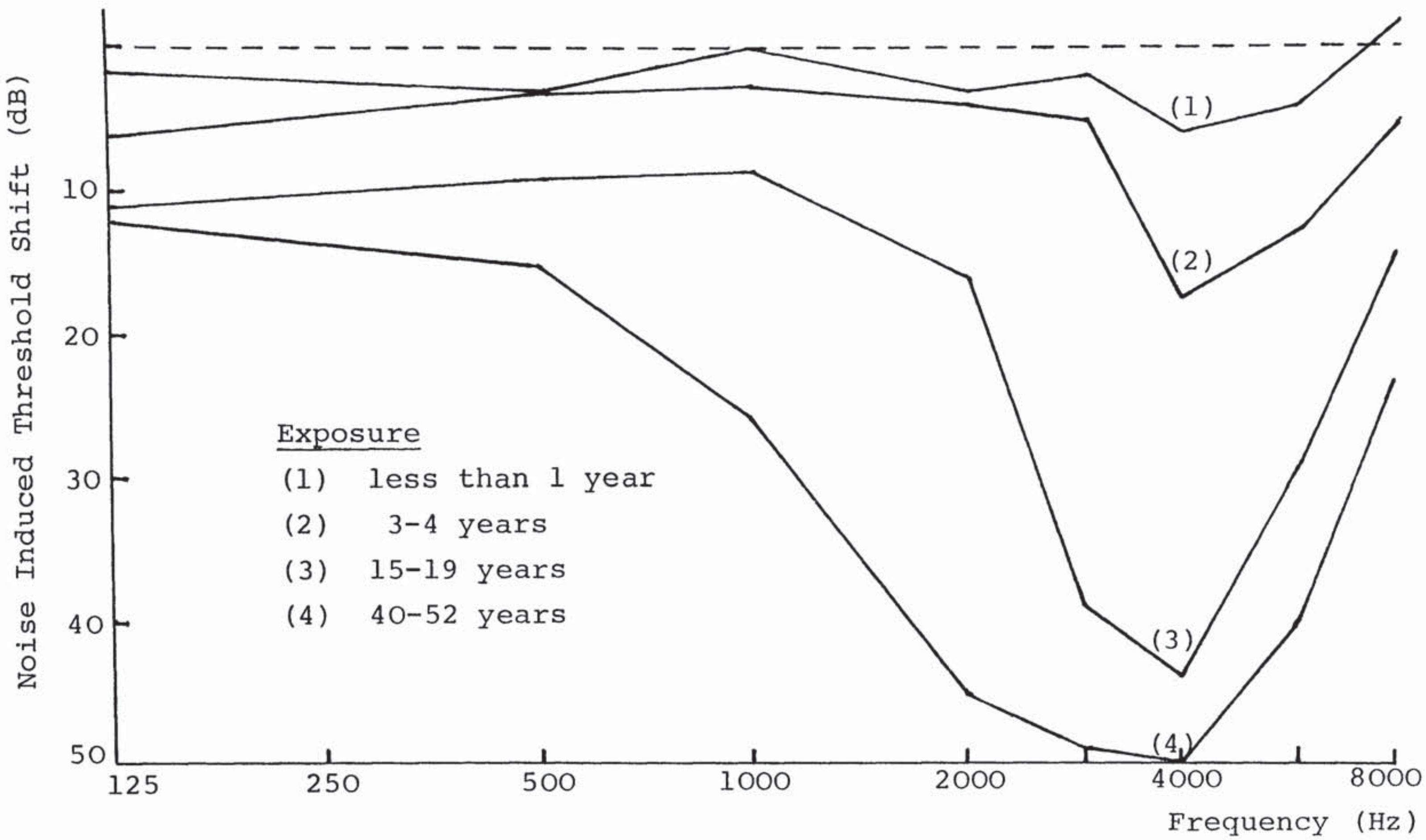
Audiogram of Person after 20 years in a Weaving Shed

Figure 5

damage occurring. Prediction of the effect of a certain noise level on a person for a given duration can only be made statistically. Thus, the risk of an individual achieving a particular degree of hearing loss can be quoted in percentage terms; or the number of people doing so out of a large sample can be predicted.

The audiograms of weavers exposed to 100 dB(A) for various periods of time were obtained by Taylor, Pearson, Mair and Burns[4]. The median hearing loss of each group at each frequency are used to produce the audiograms in Figure 6. The subjects were all women who had worked only in the weaving shed each working day for up to 52 years. The subjects had no disease damaged ears, and allowance was made for presbycusis. The measured hearing loss represents the noise induced permanent threshold shift. The audiogram of the 3-4 years group clearly shows the dip around 4 kHz. At this stage, in the median case, the hearing loss would not be noticed by the subject. The dip at 4 kHz deepens with increased exposure so that the subject may notice a loss of high frequency hearing ability. After 20 years or so the dip broadens as hearing loss becomes more apparent at lower frequencies.

The permanent threshold shift at 4 kHz is shown in measurements by Robinson[5]. The threshold shift was measured in subjects exposed for varying lengths of time



Median Hearing Loss of Groups of Weavers Exposed to 100 dB(A) for varying Lengths of Time

Figure 6

to differing levels of noise. The results are shown in Figure 7. The hearing loss is again the median of several subjects' ears. The effect of presbycusis has not been excluded, so that the effect of the noise can be compared with controls who were subject to no noise. The conclusion of many experiments of this sort is that in fact noise induced hearing loss is truly cumulative, and the damage depends on the noise energy dose however long or short the period over which it is received.

3.5 Units of Noise Measurement

In assessing the effect of noise on an individual, and the hazard of working in a particular noise environment in a factory, it is essential to consider not only the intensity of the noise, but also the duration of exposure by the individual. In fact there is a third dimension to be included; that of the frequency of the sound. The human ear is not equally responsive to all frequencies, but is more sensitive to sounds in the octave bands centred on 1 kHz, 2 kHz and 4 kHz. Above and below this range the sensitivity decreases. Although a person with normal hearing has an audiogram which is approximately zero at each of the audiometric frequencies, the zero does not correspond to an equal sound pressure level.

When measuring noise levels in factories it is

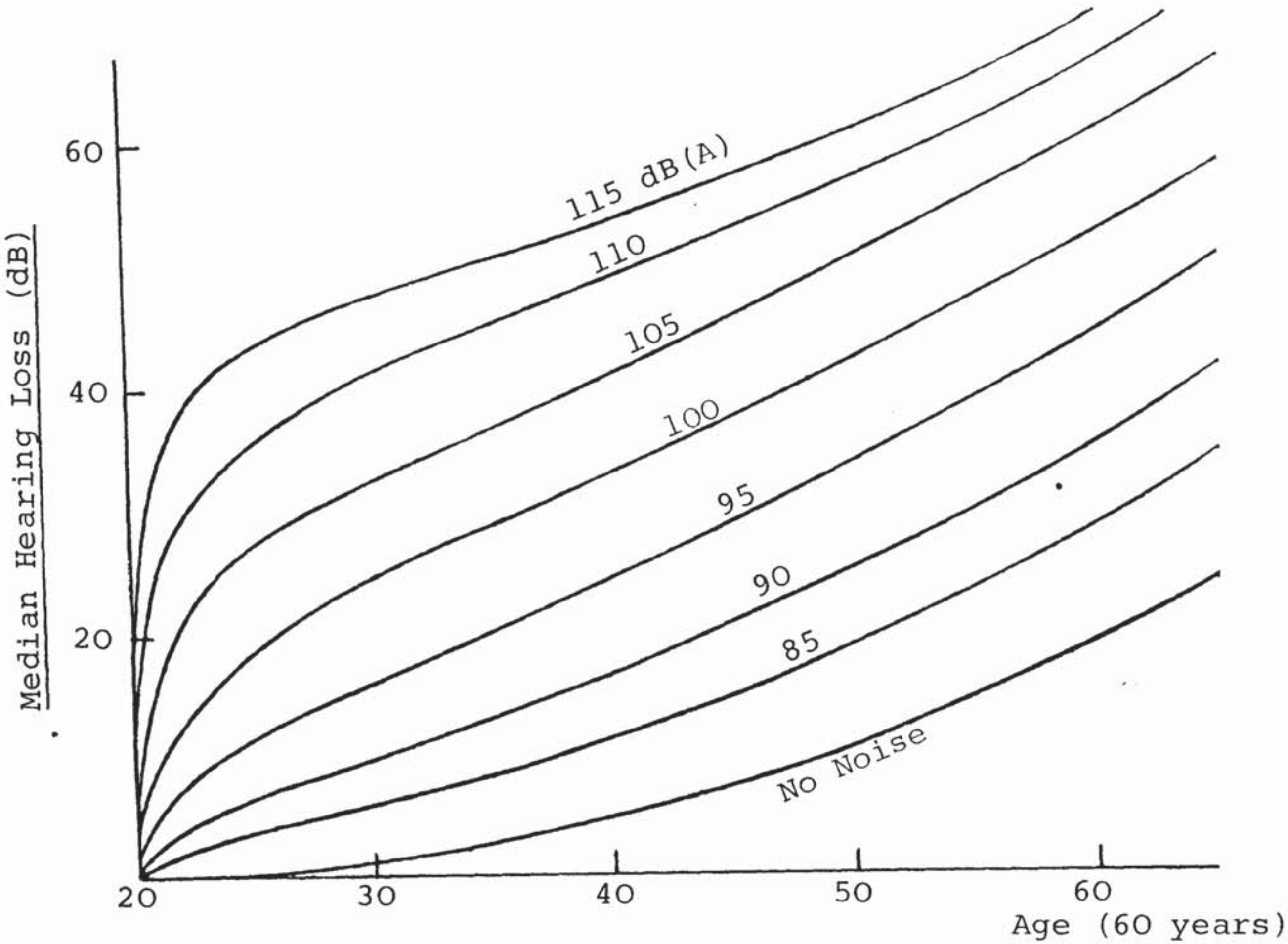


Figure 7

Hearing Loss due to Noise and Age at 4 kHz

Assuming Exposure begins at age 20

usual to use a meter which weights the sound in the same way as does the ear. Hence the unit dB(A), or 'A'-weighting decibel. The 'A'-weighting is an approximation of the weighting of the ear, strictly speaking at the threshold of hearing only, not only in the sensitivity of detection but also in sensitivity to noise induced hearing loss. One method of obtaining an 'A-weighted' noise level is to measure the octave band levels and then make the corrections shown in Table 12 before adding the octave band levels logarithmically to produce an overall level in dB(A).

The unit of dB(A) contains no information regarding the duration of exposure to that sound. The normal duration of exposure of a person in industry to noise is 8 hours each day. A measure, known as the "equivalent continuous sound level" or L_{eq}, is the constant noise level which would in the course of an eight hour period cause the same 'A-weighted' sound energy to be received as that due to the actual sound over the actual working day. L_{eq} is a measure of "sound energy dose" and includes duration as well as intensity. A person exposed to 93 dB(A) for two hours has been exposed to an L_{eq} of 87 dB(A). The relationship is given by the following equation:-

$$L_{eq} = 10 \log_{10} \frac{8}{t} 10^{L/10}$$

Octave Band Centre Frequency (Hz)	Correction (dB)
31.5	- 39.4
63	- 26.2
125	- 16.1
250	- 8.6
500	- 3.2
1000	0
2000	+ 1.2
4000	+ 1.0
8000	- 1.1
16000	- 6.6

Table 12

'A'-weighting Corrections to Octave Band Levels

Where t is the duration of noise exposure in hours

and L is the actual measured sound level in dB(A).

3.6 Defining and Enforcing a Maximum Noise Level

In order to combat hearing loss in factories it is necessary to restrict the L_{eq} to which the ear is exposed. The very wide variation in sensitivity to damage from person to person means that unfortunately there will always be a small percentage of people who suffer hearing loss however low the maximum is set. An acceptable risk of hearing loss therefore must be determined.

The number of years of exposure to high noise is clearly a factor in deciding upon an acceptable maximum noise level. The total noise immission of a person working twenty years in an L_{eq} of 90 dB(A) followed by twenty years in a quiet environment will be less than the noise immission of another working forty years in an L_{eq} of 90 dB(A). In practical terms it is not possible to make individual allowances of this sort. Forty years is usually the greatest length of time to which any single person is exposed to high noise levels, although working lifetimes of 52 years are not unknown. Figure 8 shows the percentage of persons attaining or exceeding a mean

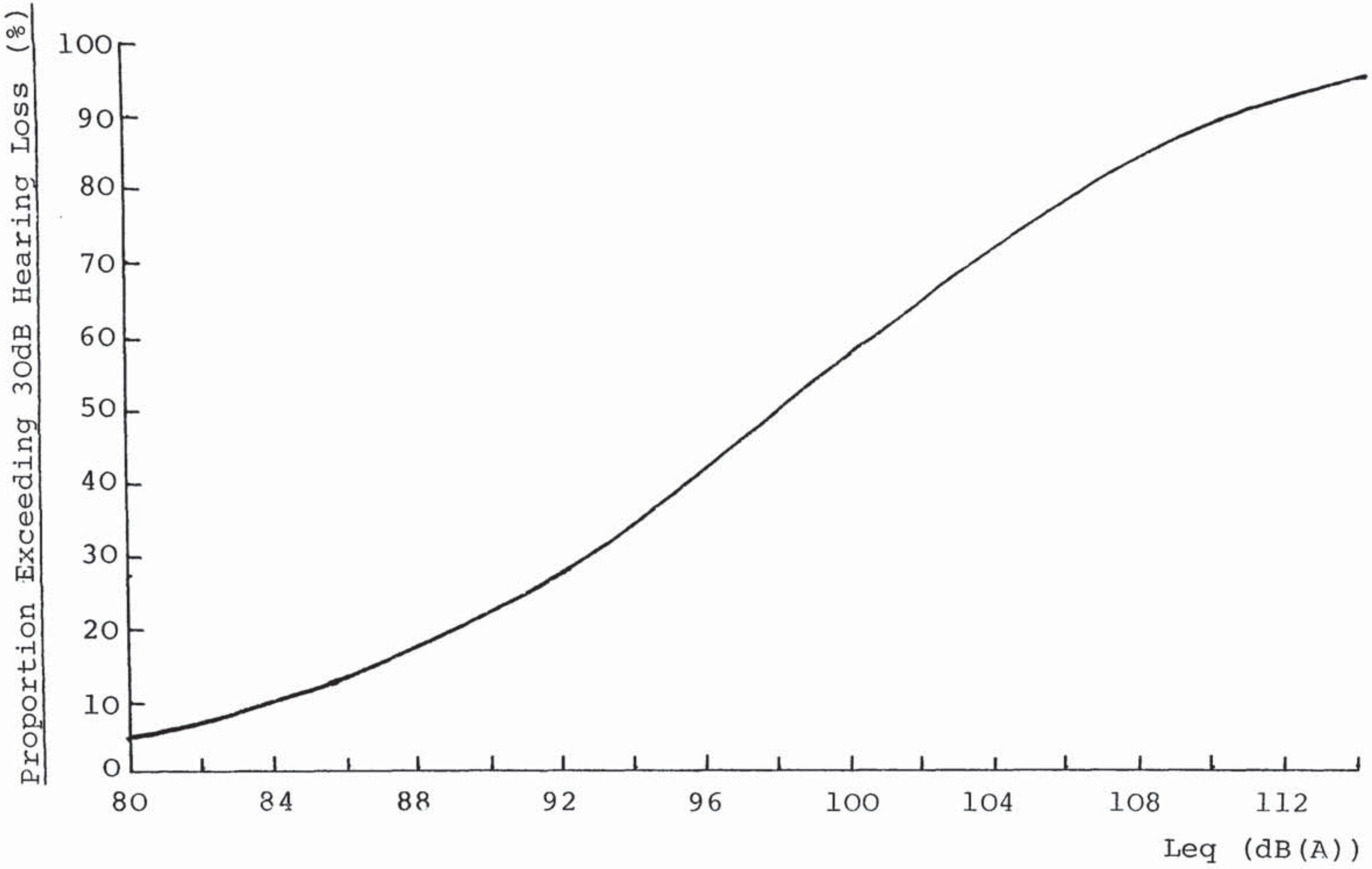


Figure 8

Variation with Sound Level of the Proportion Exceeding a 30dB Hearing Loss after 40 years Exposure hearing loss of 30 dB (the arithmetic mean of the hearing loss at the audiometric frequencies of 1 kHz, 2 kHz and 3 kHz) when reaching the age of 65 years and being exposed to various levels of L_{eq} for 40 years. The figures are taken from BS 5330[6]. A mean hearing loss of 30 dB is the point at which the loss becomes significant. It is defined as mild, and would cause difficulty in understanding faint speech.

The degree of risk to hearing which is acceptable depends on the attitude of society. Until recently hearing loss was not regarded as a serious disability. It was, and still is in many quarters, assumed to be an inevitable consequence of working in certain industries, particularly the textile industry. Even in these enlightened times the consequences have to be balanced by the cost of noise reduction, or alternatively the inconvenience to the employees of using hearing protection. The disadvantages of hearing protection in place of noise level reduction are discussed in Chapter 5.

Most countries in the developed world have set a maximum noise level to which the unprotected ear can be exposed. The 1972 Code of Practice[7] for Reducing the Exposure of Employed Persons to Noise provides the most authoritative statement in the United Kingdom on all aspects of noise in industry. The recommended maximum levels are given in section 4 of the Code.

> 4.2.1 *People should not be exposed to sound levels exceeding the limit set out ..... below, unless they are using ear protection which effectively reduces the sound level at the user's ear to or below the limits for unprotected ears .....*
>
> 4.3.1 *If exposure is continued for 8 hours in any one day, and is a reasonably steady sound, the sound level should not exceed 90 dB(A).*
>
> 4.4.1 *If exposure is for a period other than 8 hours, or if the sound level is fluctuating, an equivalent continuous sound level (L_{eq}) may be calculated and this value should not exceed 90 dB(A) .....*

The Code of Practice therefore takes an L_{eq} of 90 dB(A) as the level of maximum acceptable risk. Although the Code of Practice makes voluntary recommendations, it is supported by section 2 of the 1974 Health and Safety at Work Act [8] which deals with the general duties of employers to their employees.

2.-(1) It shall be the duty of every employer to ensure, so far as is reasonably practicable, the health, safety and welfare at work of his employees.

At the present time there is no statute which lays down the responsibilities of management regarding noise more specifically than section 2 of the Health and Safety at Work Act, with the single exception of the use of woodworking machines[9]. There is no legally defined maximum permissible noise level, except insofar as contravening the recommendations of the Code of Practice may be held to be unreasonable behaviour under section 2 of the Health and Safety at Work Act. In fact a total of 19 improvement notices to reduce noise levels were issued by H.M. Factory Inspectors in 1976. They were all complied with.

The Health and Safety Commission is the body set up by the 1974 Health and Safety at Work Act to oversee the workings of the Act. They have the power to introduce subordinate legislation under section 15 of the Act to impose restrictions on the noise conditions in which people can work in industry. They have already agreed in principle that specific noise legislation is necessary, and are considering proposals put forward by a working party.

The legislation will be based on the 1972 Code of Practice, and will probably be similar to that proposed in the document "Framing Noise Legislation"[10] produced by the Industrial Health Advisory Sub-committee on Noise. One fundamental difference, however, is likely to be the maximum recommended noise level to which the unprotected ear is exposed. In the Code of Practice the level is defined in section 4, quoted above, at an L_{eq} of 90 dB(A). The representatives on the working party from the Confederation of British Industry apparently favour a statutory maximum of 90 dB(A) in line with "Framing Noise Legislation." The Trades Union Congress representatives are pressing for a maximum as low as 80 dB(A). The most likely outcome is a compromise of 85 dB(A) or possibly 84 dB(A).

It is generally agreed that the voluntary recommendations of the Code of Practice do not provide sufficient motivation for management to reduce noise levels or ensure hearing protection is worn where necessary. The objective of the legislation is to provide the incentive for noise reduction by the selective use of Improvement Notices, and possibly Prohibition Notices, in situations where the company can afford the modifications without becoming unprofitable and therefore without risking jobs. In addition, where noise levels necessarily do exceed the maximum level, whatever it is, the legislation will make employers more aware of their responsibilities in ensuring their workers use hearing protection.

The financial implications of the requirements to be made of companies by the impending legislation are particularly important in the textile industry where the low selling price of fibre, fabrics and garments as a result of world overcapacity means that many factories are making very little profit if any from their operations. Enforced expenditure to reduce noise levels, even if technically possible, would ruin some, with the subsequent impact on unemployment. The Health and Safety Commission are well aware of this danger, but are not prepared to allow it to continue to be used as an excuse for inaction where it cannot be justified. The flexibility which will allow H.M. Factory Inspectors to enforce a limit where the company can be expected to meet it, but not otherwise, is embodied in the phrase "reasonably practicable." It is a legal term and may be incorporated in the legislation in a similar fashion to the following quotation from "Framing Noise Legislation."

48 (ii) *Where it may be shown from the noise surveys that, for any worker, L_{eq} exceeds or is likely to exceed 90 dB(A) on any day, ... all reasonably practicable steps must be taken to reduce the sound level or the duration of exposure or both, such that L_{eq} falls below 90 dB(A) or is reduced to the greatest reasonably practicable extent.*

If the term "all practicable steps" were to be employed in this context the enforcement would be conditional only upon a technical solution to the noise problem being available. H.M. Factory Inspectors would not then insist on an improvement if the alternative was to cease the noise producing operations, but if a means of reducing the level could be devised then it must be incorporated regardless of cost. There are thus three degrees of compulsion to be found in legislation affecting health and safety. There is the absolute condition which makes certain standards compulsory, and without those standards the operation of the process or machinery is prohibited. "Practicable" is the second degree where a solution must be available before the law insists on it being employed, and the third degree is "reasonably practicable" in which case the improvement must additionally be within the means of the company before it becomes a requirement. The law on noise is most likely to recognise the high cost of noise reduction in many instances and use the condition "reasonably practicable."

3.7 A Maximum Noise Level for the Courtaulds Group

On the 7th November 1977 there was a meeting of all parties in the Courtaulds Group concerned with noise. These were the Group Safety Department, the Group Medical Department, the Engineering Development Department and the Group Legal Department. One result of the meeting was for the setting up of a small working party with the purpose of producing a Group Standard on Noise. The Standard will provide a procedure for managers throughout the Group to follow when confronted with noise problems. The prime purpose will be to inform them of the central services within the Group which are available to assist them. These would include Group Medical Department, and Group Safety Department, but principally the Engineering Development Department which has had experience at dealing with most aspects of noise.

In writing the Standard it was necessary to define the level of noise which constituted a problem, for the benefit of the factory manager. This required the specification of a maximum noise level, which if exceeded in any area required the use of hearing protection by those working in that area. It also required a detailed description of the way in which noise measurements are to be made. The Standard is still at the discussion stage, but it will include advice and recommendations on all aspects of noise in industry. The complete Standard is presented in Appendix 1, but the individual aspects are discussed in the context of the relevant part of the research programme. In this way it can be seen how research provided the experience and information which led to the production of a practical standard. The cornerstone of any noise standard is the choice of maximum noise level.

There is clearly no justification for recommending a noise limit at a higher level than the L_{eq} of 90 dB(A) set by the 1972 Code of Practice. To do so would be a serious neglect of duty on the part of the people who make the recommendations, and could lead to prosecution under section 7 of the Health and Safety at Work Act. A limit as low as 80 dB(A) would be totally impractical, since it is very rare to find a factory premise containing machinery where this level is not exceeded. If the choice is restricted to levels differing by a least 5 decibels, the candidates are either 90 dB(A) or 85 dB(A).

Although, as already stated, the current limit is 90 dB(A), a maximum level of 80 dB(A) would probably be anticipating legislation for industry as a whole. If 85 dB(A) becomes the statutory maximum, it would again be irresponsible for a central body in the Courtaulds Group to regard higher levels as acceptable, and make recommendations accordingly. Legislation is sufficiently imminent on this point that a document circulated throughout the Group recommending a limit of 90 dB(A) would have to be amended within a short period of time to 85 dB(A). On the other hand, a company such as Courtaulds would lose nothing in being seen to be one step ahead of the current minimum standard recommended by the Code of Practice. It should be remembered that the Code of Practice states in section 4, in addition to those parts already quoted:

> *4.1.1 "The limits set out in this section should be regarded as maximum acceptable levels and not as desirable levels. Where it is reasonably practicable to do so it is desirable for the sound to be reduced to lower levels."*

The arguments in favour of an 85 dB(A) target are countered by the practical problems of implementation. The graph in Figure 9 indicates the rapid rise in the number of factories and people likely to be included as the limit is lowered. The statistics are taken from a survey of American manufacturing industry by Karplus and Bonvallet[11] and cannot be used as anything but an approximate guide to the situation in a company such as Courtaulds. However, experience shows that an increase in numbers affected if the limit was lowered from 90 to 85 dB(A) would be of the order of 50%.

The consequences of introducing a lower limit are two fold. Firstly more machines would require quietening, and those above 90 dB(A) would require an extra 5 dB attenuation. Secondly there would be a large increase in the number of people expected to use hearing protection where noise levels cannot be immediately reduced. There are major disadvantages associated with each of these consequences. Managers confronted with such a huge task of machine noise reduction are correspondingly more likely to make no attempt to comply, and therefore to take the relatively easy option of providing ear protection. Without even the grudging support of factory managers a noise reduction programme stands little chance of success. In the less satisfactory situation where noise reduction

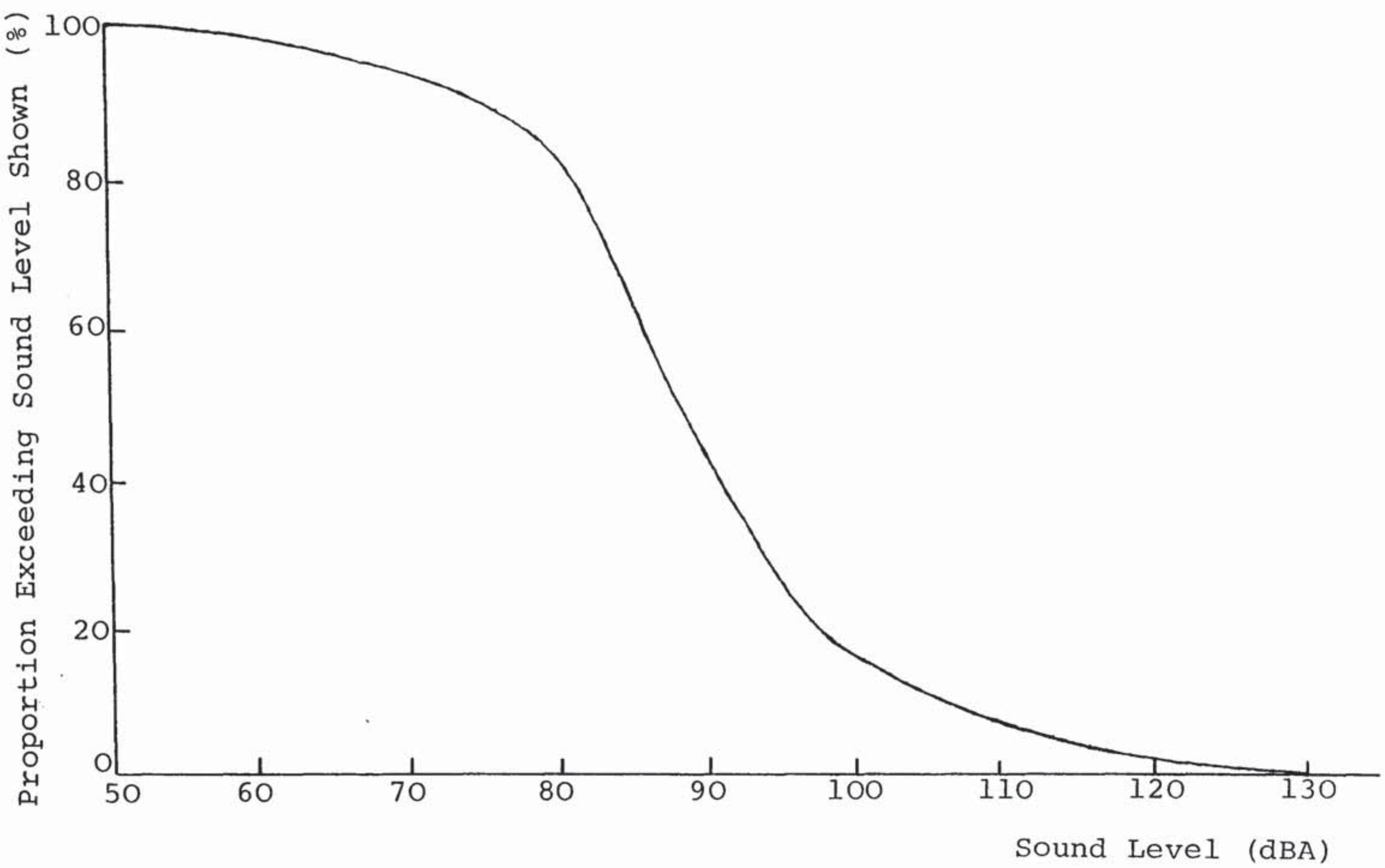


Figure 9

Distribution of Sound Levels in Manufacturing Industry is not considered reasonably practicable, the problem will be in persuading those working in noise levels of between 85 and 90 dB(A) that they should use hearing protection. They are, for example, women working on sewing machines in garment make-up areas who have become accustomed to working in those conditions and do not regard them as being excessively noisy. Not only would it be difficult to persuade such people, but the result would be to divert resources from other parts of the industry where noise levels are much greater and hearing protection essential.

In conclusion, therefore, it should be said that there is justification for believing a limit of 85 dB(A) is less likely to result in extensive noise reduction, than would a limit of 90 dB(A). However, in view of the prevailing climate and the expected legislation, a target maximum noise level of 85 dB(A) should be recommended in the Group Standard. If any employee works in an L_{eq} of greater than 85 dB(A) he should use hearing protection which reduce the L_{eq} to which he is exposed to less than 85 dB(A). Mention should also be made of the fact that 90 dB(A) is the present maximum recommended level in the Code of Practice and that reducing exposure to an L_{eq} of 90 dB(A) is the priority. This would provide an incentive to management to reduce levels as far as possible if 85 dB(A) is not readily achievable.

4

Noise Surveys

Chapter 4

Noise Surveys

4.1 Introduction

A survey of noise levels is the first stage of a factory noise control programme. It shows whether or not noise levels are excessive. If they are it will show the the factory manager the degree of noise reduction required to remove the hazard. A thorough survey should also make clear which specific areas of the factory have high noise levels, and it should indicate which machines are responsible for the noise. The manager should then know which of his employees are at risk, and the steps he must take to protect them from the hazard or remove it altogether.

The Engineering Development Department of Courtaulds has performed many surveys in the Courtaulds Group. They have been made at the request of factory managers because the policy of the Department is to make a charge for the service. The charge is made through the internal accounting system. A typical survey takes one day, and the approximate charge for a small site which can be covered in a day is currently £70 plus travelling expenses. The result is that the premises surveyed are only those where the manager is concerned about noise levels, either on his own initiative, or following complaints from employees. The 1972 Code of Practice states that all places where the limit (see Chapter 3, section 6) may be exceeded should be surveyed. This is soon to become an explicit statutory duty.

In fact, most sites in the Courtaulds Group with noise levels above 90 dB(A) have been surveyed at some stage in the past. Many of the surveys were sketchy, however, and some are of dubious accuracy. If the recommended maximum level is reduced to 85 dB(A), many other sites will require surveys. Re-surveying will be necessary in factories where alterations have been made, such as those where machinery has been replaced or moved. Noise levels also frequently change if there is an increase in production speed. It is important that a method of noise measurement is clearly defined and adopted throughout the Group to prevent ambiguity in interpreting results. At present, noise surveys are performed by many individuals, some of whom are experienced in the use of the instruments, and some of whom are not. An increasing number of factories have their own sound level meters, and this practice should be encouraged. The latter part of this Chapter describes recommended general directions for making noise surveys, and these will be included in the Group Standard on noise. They should be of assistance to anyone in the Group who wishes to make his own measurements, and they should also ensure that the Group will eventually be covered by a set of surveys which are thorough and accurate.

4.2 A Survey of a Hosiery Factory

One of the surveys made during the course of the project was at the Courtaulds Hosiery factory at Langley Mill in Derbyshire. The report, which was sent to the Works Manager of the factory, is reproduced in Appendix 2. It is not intended as a perfect example of a survey, but to illustrate this particular aspect of the work included in the project, as a basis for discussion of the kind of information which should be included in a noise survey report.

The Langley Mill factory makes "fully-fashioned" and "seam-free" hosiery garments (see Chapter 2, Section 7). There are three knitting areas, and two additional areas in which the stockings or tights are finished. The latter contain sewing machines, at which women sit performing operations known, regardless of the garment type, as "turn-seam-turn."

'A'-weighted noise levels were measured at positions a constant distance apart in each room. Each individual measurement is recorded in the report on a diagram, which also serves to show the relative positions of the machines. A summary of noise levels is produced in the text. In the knitting areas the meter was held centrally between adjacent rows of machines. This is the position in which an operator would normally stand, although he will, on occasions, lean over the machines. In these situations, where there are a large number of similar machines in a relatively small area, movement of the sound level meter away from the central measuring position appears to make little difference to the reading. However, the noise level should be checked at the closest approach of the operator's head to a machine, and the reading recorded.

Octave band levels were measured at one or two selected positions in each room; usually those positions which show the highest 'A'-weighted levels. These are for reference purposes. They assist in the selection of suitable hearing protection, and are also significant if absorption material is required for the walls of the room in future.

On the occasion of this particular survey a difficulty was encountered in the "turn-seam-turn" areas. Although noise levels were measured in the aisles, the operators sit at their sewing machines. The major noise source was a tube at each machine into which air was drawn by a central vacuum unit. The partial vacuum at the tube assisted the women in making the "turning" operation, and also acted as a collection device by drawing the completed garment to the central vacuum unit. Higher noise levels would have been measured at the operators' ears than in the aisles. In view of delicate wage negotiations it was agreed that the operators should not be unduly alarmed by having a sound level meter placed adjacent to their ears. The report made clear that the exposure to noise of those working at "turn-seam-turn" machines is excessive. The report is available for safety representatives to see, and the works manager is prepared to implement proposals for reducing noise levels. The example does illustrate a potential disadvantage of the policy of the factory manager contracting the services of a central department. If the survey work were compulsory, and centrally funded, the manager would not determine which noise levels were measured and which are not.

The report begins with a description of the equipment used in making the noise measurements. The recommendations of the 1972 Code of Practice are quoted directly where relevant, and the measures necessary to meet them are described. Advice on the application of the 1972 Code of Practice and the Health and Safety at Work Act 1974 to the particular situation is just one important feature of noise surveys carried out by specialists which would be missed if the survey were by a non-specialist.

In addition, suggestions for reducing noise levels could be included, together with approximate costs of alternative methods and the predicted resulting noise levels.

4.3 A Standard Procedure for Noise Surveys

A total of eleven noise surveys ~~have~~ has been made as part of the project. The experience gained from these exercises, combined with a study of noise surveys performed by others both inside and outside the Group, have led to a recommended procedure for conducting such surveys. The procedure is to become a part of the Group Standard on noise, and is reproduced in Section 1 of Appendix 1.

Noise surveys should be undertaken if there is any likelihood that employees are exposed to noise levels greater than 85 dB(A). They should be made by someone who has at least a basic training in noise measurement techniques. A number of suitable one or two day courses are available. In the future, courses could be arranged for people who are likely to make regular checks on noise levels, covering other aspects of noise control as well as methods of measurement. The noise control unit of Lucas-CAV have organised such courses for employees in their factories, and have had an estimated 2% of their total workforce attend. In the first instance, noise surveys should be conducted by experienced personnel. A greater accuracy and uniformity would be achieved. Subsequent checks by a site engineer or safety officer could then be made on a regular monitoring basis using a small, inexpensive sound level meter.

There are two British Standards referring to sound level meters used for measuring continuous noise. The meters are graded as industrial[12] or precision[13], depending on the British Standard they meet. Maximum permitted tolerances are defined for measuring the sound pressure level in each of the audio octave bands. A typical broadband octave band analysis of sound from a weft knitting machine is shown in Table 13. If a sound level meter were to measure the sound inaccurately at the upper and lower limits of its tolerances, the readings obtained in each octave band are also shown in Table 13. The overall 'A'-weighted sound pressure level of the noise from the knitting machine is 90.5 dB(A). A precision grade sound level meter would read 91.4 dB(A) or 89.0 dB(A) at the limits of its tolerances. An industrial grade sound level meter would read 94.9 dB(A) or 87.3 dB(A), a range of 7.6 dB.

Precision sound level meters can therefore be read to the nearest whole decibel, and an accuracy of

Octave Band Frequency (Hz)	Typical Octave Band Levels of a Weft Knitting Machine (dB)	Measured Levels at Limits of Tolerances (dB)			
		Industrial Grade		Precision Grade	
		Upper	Lower	Upper	Lower
62.5	74	78	70	77	71
125	74	77	71	75	73
250	76	79	73	77	75
500	79	82	76	80	78
1000	82	84	80	83	81
2000	85	88	82	86	84
4000	84	89.5	80	85	83
8000	84	90	78	85.5	81
16000	76	82	$-\infty$	79	$-\infty$
'A'-weighted	90.5 dB(A)	94.9	87.3	91.4	89.0

Table 13 Maximum Tolerances for Industrial and Precision Grade Sound Level Meters Permitted by British Standards

approximately ± 1 dB can be claimed. This assumes no error in reading the meter, which is only true if the sound is very steady. Industrial grade sound level meters, which are the type commonly purchased by individual factories, are considerably less accurate. The electronic circuits of sound level meters are temperature sensitive, and therefore it is essential for a meter to be calibrated immediately before measurements are made. A check should also be made afterwards to ensure the calibration has not drifted. The importance of calibration is often not appreciated by those responsible for measuring noise levels on site, and sound level meters are known to exist without any available method of calibration.

In the Group Standard, attention is drawn to problems of measuring time-varying noise levels. If the level fluctuates by about ± 2 dB the mean can usually be estimated accurately by eye. Greater fluctuations, or those taking place very slowly, require the use of a statistical analyser, such as the Brüel & Kjaer Noise Level Analyser (type 4426) owned by the Engineering Development Department. It is also pointed out that the measurement of impulsive sounds requires specialist equipment.

The normal position for holding the sound level meter is at a height of 1.5 metres if the person usually stands at that position, or at 1.2 metres if he usually sits. The meter should be held in a horizontal position as close as possible to that of the operators' ears when working at the machine. It is incorrect to hold the meter at a distance of one metre, as is often specified, if the operator habitually brings his head closer than one metre. Conversely, an artifically high reading is obtained if the meter is held too close to a machine.

Exposure to varying noise levels during the course of a day, for example moving from one area to another, means L_{eq} must be obtained for every employee. The Group Standard includes an explanation of the circumstances in which L_{eq} is preferable to uncorrected noise level measurements, and reference is made to Appendix 3 of the 1972 Code of Practice for the method of calculation.

Finally the Group Standard includes a checklist of the information which should be included in the noise survey reports. It will ensure that the survey is understood by someone not familiar with the factory, and in order that the survey may be repeated at a later stage for comparison purposes.

a. *The name of the person carrying out noise survey, and date of measurement.*

b. *A plan of each room where appropriate, with all machines and measurement positions marked.*

c. *An indication of which machines were in operation at the time of measurement.*

d. *The height of the meter above the ground.*

e. *The distance from microphone to machine if the measurement position is close to it.*

f. *Type of sound level meter used.*

g. *The settings on the sound level meter, and calibration information as defined above.*

h. L_{eq} *if calculated.*

i. *The number of persons normally employed in the area.*

j. *Any other prevalent conditions which would enable the measurements to be repeated at a later date, such as machine loading or machine speeds.*

4.4 Conclusions

Noise surveying is an important part of a noise reduction programme. Surveys should preferably be carried out by specialists, at least in the first instance. Local factory managers who wish to purchase their own sound level meters for regular noise level monitoring should be encouraged to do so, although they should be aware of the limitations of industrial grade instruments. Anyone who undertakes noise surveys should ideally have some training in the techniques, and should follow a set practice. To this end, the recommendations in Section 2 of the Group Standard (Appendix 1) should be circulated throughout the Group. A copy of every noise survey should be filed with a central department. The Engineering Development Department should be equipped to carry out noise surveys at the request of factory managers, and their work should preferably be funded centrally. Proposals for running short courses in techniques of noise control and noise measurement should also be considered.

5

Hearing Protection and Audiometry

Chapter 5

Hearing Protection and Audiometry

5.1 Introduction

Noise is an unpleasant by-product of all machines to some degree. Although noise reduction is possible in a high proportion of industrial processes, there are some in which it is difficult to conceive of any means of achieving safe levels. Total automation is the only solution to the hearing loss problem in, for example, the drop-forging and boilermaking industries, so that no one works in the hazardous noise levels. In industries where noise reduction is technically possible, it will be many years before the investment can be made in new and expensive plant. Quiet factories are a luxury which we will have to earn gradually. However, if workers are to be subjected to high noise levels for either the short term, or the indefinite future, their hearing must be protected from the noise by attenuating the sound reaching the ear. The hearing protection should be designed and used in such a way that, although the person may be working in high noise levels, the noise energy reaching the tympanic membrane is not hazardous to any significant degree.

5.2 The Use of Hearing Protection

There are two fundamentally different types of personal hearing protection. Ear muffs act entirely outside the ear, and cover the exterior part of the ear, or pinna. Others are placed either partly or wholly in the ear canal to impede the passage of sound.

Ear muffs consist of two cups which cover the whole exterior part of the ear and form an air-tight seal against the head. They are held in position normally by an elastic clip band which passes over, and rests on, the ear. The positions of the cups are usually adjustable on the clip to fit all sizes of head. The cup is of a plastic material, and contains some sound absorbent material. The choice of materials is dictated by the attenuation required at each part of the frequency spectrum. Higher frequencies are generally easier to attenuate than lower frequencies. The seal between cup and head is made by either an air-filled or water-filled cushion. The latter tends to be more effective. The cushion also makes the ear muffs comfortable to wear for long periods, particularly since the connecting band has to exert a substantial force on the cups to maintain the seal.

Ear muffs are capable of achieving attenuations in excess of 25 dB, providing they are correctly used. The attenuation depends critically upon the effectiveness of the seal, which may be reduced in a number of ways:-

1. Distortion of the headband results in insufficient pressure. This is sometimes deliberately caused by the wearer in order to make the ear muffs more comfortable.

2. Damage to the cushion.

3. The wearing of spectacles, including safety spectacles, under the ear muffs inevitably reduces the effectiveness of the seal.

4. Similarly, hair under the cushion may reduce the effectiveness of the seal.

In addition, attentuation will also be lost if the cup itself is damaged, or if the absorbent material is removed.

Certain types of ear plug which are partly pushed into the ear canal are as effective as basic ear muffs. However they have to be individually fitted by a medical expert. The foam ear plugs, which are compressable do not have that particular disadvantage, since the foam expands inside the ear canal to provide an air-tight seal. Both methods create hygiene problems because they are normally used repeatedly. Ear down is a disposable acoustically absorbant material, and is used in the way one would use cotton wool. However the attenuation is only 15 dB, and is not sufficient in areas where the noise level exceeds 100 dB(A).

All types of hearing protection require the wearer to have some degree of training in their effective use. Even ear down can be incorrectly fitted. Ear plugs and foam should be regularly replaced for hygiene reasons, preferably once a week, and ear muffs must be replaced if they are damaged. The cushions are usually detachable from the cups, and must be washed regularly. If spectacles are worn the side pieces which rest on the ear should be as small as possible in cross section.

The main problem associated with hearing protection is in persuading people to use it. It is not sufficient for an employer to place an ear down dispenser in the foreman's office, which is often the case. The employer must make all those working in the high noise aware of the hazard, and ensure hearing protection is used.

Hearing protection is an inferior alternative to reducing noise levels in the factory, and should only be used where noise reduction is not reasonably practicable. There are many disadvantages in the use of hearing protection, (Acton 14) and therefore it should never be regarded as an alternative to reducing noise at source.

1. The effectiveness of hearing protectors is easily lost by incorrect use and the causes discussed above. Such deficiencies are often not noticeable to the wearer, or to management by casual inspection.

2. There are problems of hygiene associated with using hearing protection in an industrial environment, particularly the methods which require the insertion of an attenuator into the ear canal.

3. Ear protection is uncomfortable to use for long periods, particularly in the hot, humid atmospheres which are found in many of the textile factories.

4. Conversation is more difficult since attenuation is not constant at all frequencies.

5. Hearing protection must be used continuously while the wearer is in an area of high noise. The overall effectiveness of the protection is dramatically reduced by removing it for short periods, for example to talk with a colleague or as a momentary relief from the discomfort. The equivalent continuous benefit of wearing ear muffs with a nominal attenuation of 35 dB for a proportion of the total time exposed to high noise is shown in Figure 10. If the muffs are removed for only 1% of the period, the effective attentuation is reduced to 19 dB.

5.3 Audiometry

If factory workers are to continue to work in high noise level areas, protected from the hazard only by a method which is known to be fallable, there are clearly advantages in being able to measure the state of each person's hearing. The measurement of hearing, or audiometry, is a respected quantitative science in widespread use throughout the world.

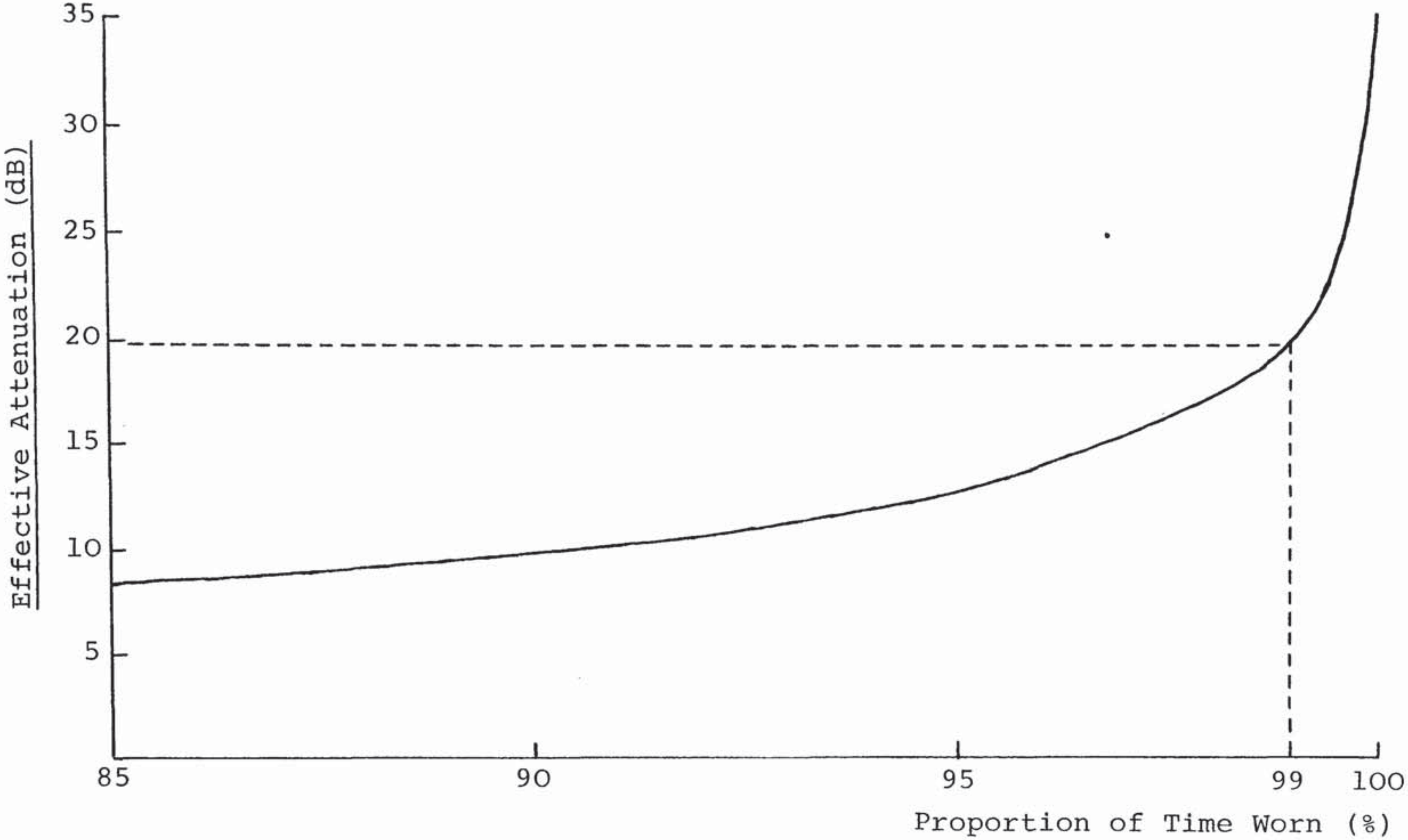


Figure 10

Effectiveness of Ear Muffs with a Nominal Attenuation of 35 dB worn for a proportion of the Exposure Time

The most common technique of audiometry is pure tone air-conduction audiometry. Other methods, such as bone conduction audiometry and speech audiometry are used in the diagnosis of hearing defects. Pure tone air-conduction audiometry is adequate for measuring noise-induced hearing loss. The subject sits wearing a pair of ear phones in a sound-proof booth. A pure tone sound of two second duration, repeated every four seconds, is presented to one ear, and the intensity of the sound is either increased from a very low level until the sound is audible to the subject, or reduced from a higher level until the sound becomes inaudible. The subject holds a push button switch which he is previously asked to press, and keep pressed, whenever he can hear the tone. Manual audiometers measure the hearing loss at a single frequency and the exercise is then repeated at another frequencey. The British Standard 15 for pure tone audiometers specifies eight frequencies 0.25, 0.5, 1.0, 2.0, 3.0, 4.0, 6.0 and 8.0 kHz. The usual procedure is to approach the threshold intensity both from above and below. The recorded threshold is the arithmetic mean of the ascending and descending thresholds, if they are found to differ. The test is made separately on each ear.

A quicker method of measuring audiograms is the self recording type. It is shown in diagramatic form in

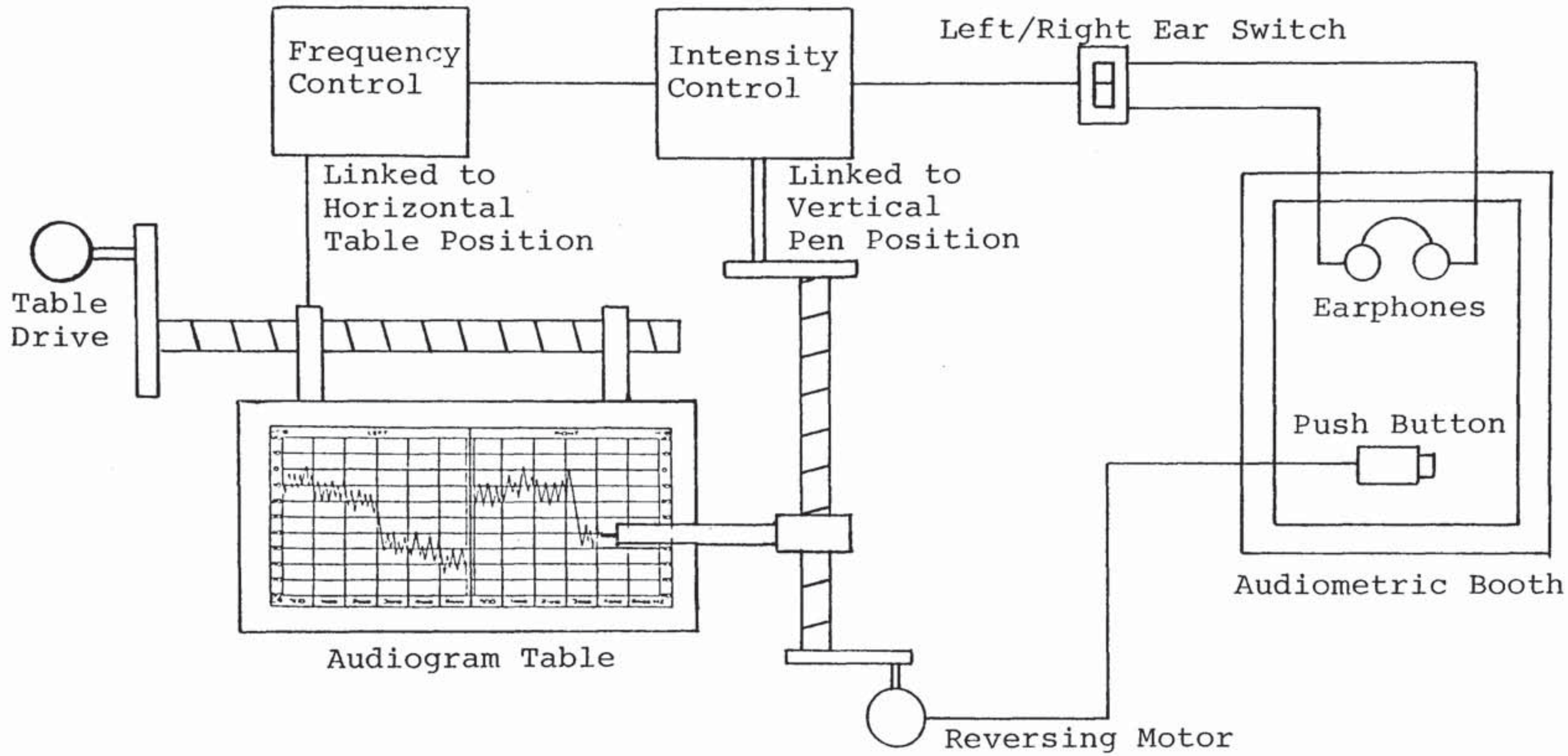


Figure 11

Diagram of a Self-Recording Audiometer

Figure 11. The intermittent pure tone scans the frequency range over a period of about six minutes. The intensity control increase and decreases the sound level continuously. The push button position determines whether the intensity control increases or decreases the intensity. If the push button is in a released position, indicating that the subject cannot hear the test tone, the intensity automatically increases. As soon as the button is pressed, at the level the test tone becomes audible to the subject, the intensity automatically begins to decrease. Similarly, when the button is again released the intensity begins to increase. The frequency of the test tone and the intensity of the signal at any instant are recorded by the position of a pen on a pen-recorder. The horizontal axis shows the frequency of the test tone, and the vertical axis the intensity. The resulting trace, of which Figure 12 is an example, displays the alternating ascending and descending intensity superimposed on the frequency scan. The two traces, one for each ear, are obtained separately.

The audiogram is obtained by drawing a curve as close as possible to the centre points (arithmetic means) of each leg of the zig-zag trace. The vertical scale is calibrated in decibels, with the zero level at each frequency given by the threshold of hearing of a normal, young adult. Zero does not therefore correspond to the

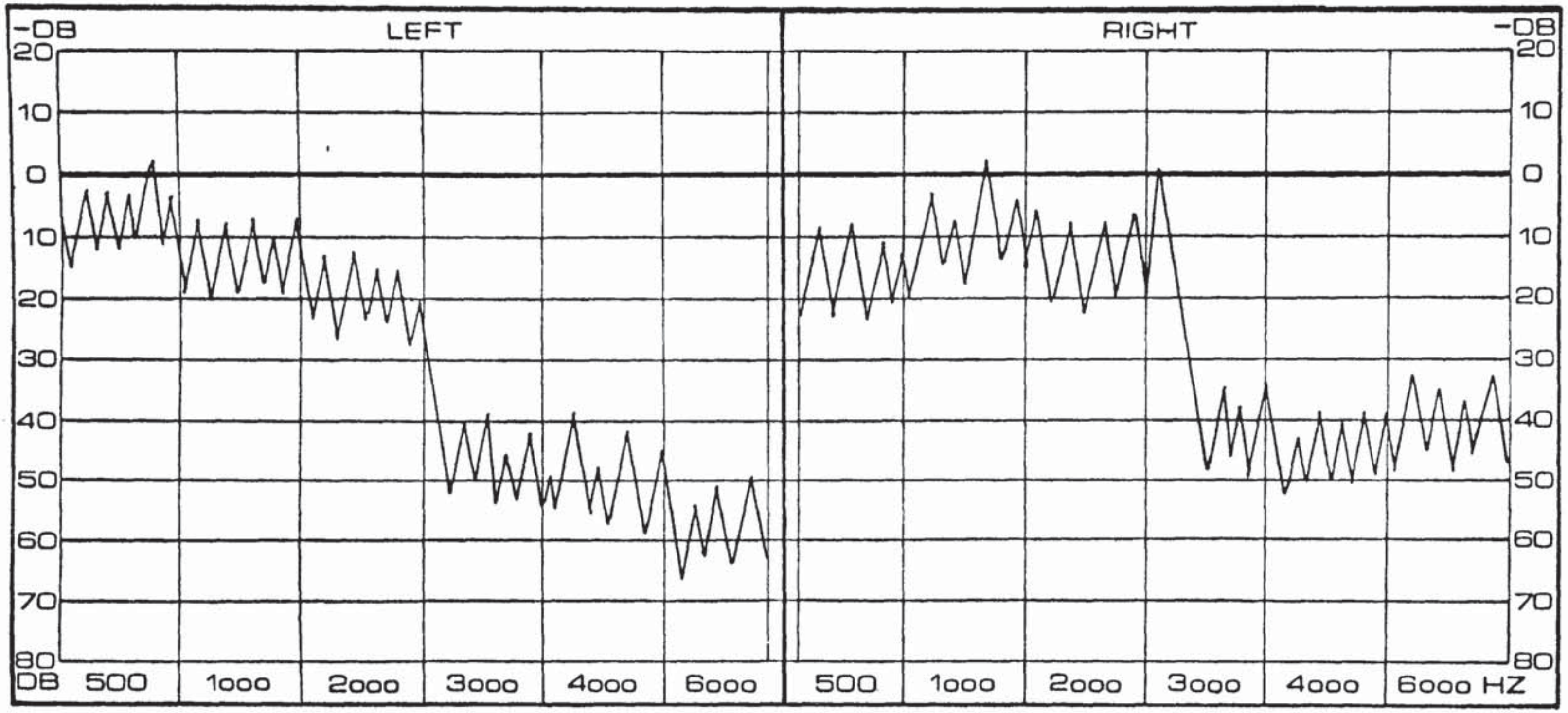


Figure 12

Self Recorded Audiogram of A Male Hammer Driver

Age 31 with 10 Years Exposure

same sound pressure level at all frequencies, for the reasons described in Chapter 3. A positive threshold shift implies a loss in hearing. A negative threshold shift means the hearing of the subject is better at that frequency than would be expected in a normal young adult.

There are two sources of systematic error in making audiometric tests. Firstly the test tone may be masked by excessive extraneous noise, and an artificially high threshold will be recorded. Not only must the earphones attenuate as much as possible, but also the subject must sit in a booth of high attenuation and insulated from vibrations. The booth should be situated in a quiet part of the factory. The second possible cause of error is due to temporary threshold shift (TTS). Audiometry is normally used to measure permanent threshold shift (PTS), and the subject should therefore not be suffering from TTS. Ideally, the test should be made after at least a weekend away from high noise levels. In practice this is not possible in many cases, but the minimum respite from high noise should be twelve hours. This can be achieved by ensuring the subjects wear good hearing protection continuously on the day of the test, until it is completed.

A single figure for hearing level is often quoted, and is obtained from the audiogram. There are several methods in use, but the most common is that recommended by the Committee on Conservation of Hearing of the American Academy of Ophthalmology and Otolaryngology (AAOO)[16]. It is the average of the threshold shift at 0.5, 1 and 2 kHz in the better ear. Table 14 shows the ratings which correspond to measured average hearing levels, and the effect such a hearing loss has on the individuals ability to understand ordinary speech.

5.4 Audiometry in Industry

Audiometry provides an important tool in a programme of hearing conservation. Noise levels can be reduced, hearing protection can be provided and worn, but audiometry is the ultimate test of success. However, the widespread introduction of audiometry into industry in the United Kingdom is not considered desirable by many. The Health and Safety Executive Working Group on Audiometry have recently circulated a discussion document[17] to interested parties. In the introduction the document states, in reference to the question of whether or not the the introduction of audiometry should be recommended:-

> *It must be recognised that this aspect of the subject gives rise to some of the*

Average Hearing Level (dB)	Degree of Handicap	Ability to Understand Ordinary Speed
Less than 25	Not significant	No significant difficulty
25 - 40	Mild	Difficulty with faint speech
40 - 55	Moderate	Frequent difficulty with normal speech
55 - 70	Marked	Frequent difficulty with loud speech
70 - 90	Severe	Shouted or amplified speech only understood
90 or above	Extreme	Even amplified speech not understood

Table 14

The Effect of Hearing Handicap on Understanding Speech *most difficult problems, since it is necessary to stike a balance between the results of introducing an audiometric programme and the costs, both financial and in skilled manpower. At present, the opinions of those involved in occupational health and safety differ on this subject and the Working Party considers that a wider discussion is needed before any firm view can be taken on the question of the circumstances under which audiometry ought to be introduced.*

Audiometry could be used merely in pre-employment screening as part of the normal, general medical examination. It would provide a baseline, so that both employer and employee are aware at any subsequent stage of the contribution his current work has made to his total hearing loss. This aspect is particularly significant in relation to claims in the civil courts for damage to hearing (discussed further in Chapter 6). The greatest division of opinion is over the use of audiometry for monitoring the hearing levels of persons working in high noise environments. The benefits of an audiometric monitoring service are:-

1. Those employees with particularly

sensitive hearing would be identifiable by having regular, significant reductions in hearing level over a period of years.

2. The effective use of hearing protection can be ensured by identifying individual cases where an unexpectedly large hearing loss has occurred in one period between tests. Close attention would be paid to these cases by checking their protection devices for damage and by ensuring they understand the correct method of use.

3. As a method of education and persuasion in running a hearing protection programme. Many employees are very reluctant to use hearing protection, so if evidence that they have lost part of their hearing could be shown to them, a powerful practical demonstration of the necessity of using hearing protection would be available. For those who are converted, the audiogram would serve as a source of encouragement and confirmation that using hearing protection is worthwhile.

The value of audiometry as a method of identifying those with sensitive ears is very doubtful. Howell[18] was unable to discern any correlation between the threshold level amongst 449 male manual steelworkers, and the subsequent hearing loss as measured by a repeat audiogram 6-8 years later. By the time the identification is made a significant threshold shift will have developed, since sensitivity can only be proved by a series of tests over a period of several years. It is not possible at present to identify a person with sensitive hearing from a single audiogram. For this reason, pre-employment tests could not be used to reject applicants who are prone to noise-induced hearing loss. If, after a series of tests over a period of years, it becomes clear that a person has sensitive hearing, he could then be moved from his job in the high noise area. However, in the textile industry, all operators and ancilliary workers are often exposed to similar noise levels, and there may be no suitable alternative. He could be asked or advised to leave, but in general people are less concerned about losing their hearing than they are about losing their job. Identification of sensitive ears may be possible in factories where there are noise levels greater than 100 dB(A) since the annual change in permanent threshold shift may be dramatic. However, before an expensive audiometry programme is undertaken it is essential to decide the action to be taken with those who are found to be sensitive.

The second argument for audiometry is as a check on the success of a hearing protection programme. Again the benefits may not be as great as they might first appear. The discussion document[17] recommends a maximum period between tests of three years. Tests more often than once a year would be impractical. Therefore, in order to identify a person, who, in one particular year was not using hearing projection effectively, there would have to be a significant difference between that and the preceeding years. Thus, the method would not identify the employees who are careless to the same degree throughout their working lift. It would only point out those whose hearing protection has become damaged, and then only after a long period of use of the damaged equipment.

The accuracy of measurement of hearing level is an important factor in assessing its value. Errors arise from a combination of inaccuracy in measuring the sound pressure level to which the ear is being exposed at the time of test, and the variability in the judgement of the threshold by the subject. If measurements are repeated on the same person, removing and replacing the earphones each time, the measured thresholds form a normal distribution curve. The standard deviation of the curve has been estimated by Robinson[19] to be 6 dB at middle frequencies, and greater at higher and lower frequencies. The actual hearing level will differ from the measured hearing level by at least 6 dB in 32% of cases, and by at least 12 dB in 5% of cases. In comparing audiograms repeated at yearly intervals, an annual deterioration in hearing level of 10 dB would be the minimum change indicating a true threshold shift with any degree of certainty. This must prevent audiometry being of benefit in assessing the effectiveness of hearing conservation measures in individuals over a period as short as one year. Accuracy of testing could be improved statistically by calculating the mean of several measurements. The cost of audiometry, discussed below, makes this an impracticable alternative.

The third argument in favour of audiometry is its use as a propaganda weapon in persuading employees to use hearing protection. It would be difficult to determine quantitatively the validity of this argument, but the practical experience of those engaged in audiometry in the National Association of Drop Forgers and Stampers, and others in the drop forging industry, is convincing. The following is a quotation from the literature to members by the National Association of Drop Forgers and Stampers recommending the use of audiometry to encourage the use of hearing protection.

> *"We have found that audiometry is a most effective persuasion. Every man tested is*

shown his own audiogram, and it is explained to him how this relates to the average hearing for his age. If his is below average, it is explained to him that he must protect what he has left if he is to avoid a deaf old age. This seems to be the most effective way of instilling a sense of urgency."

Although, the Association offers an audiometry service to its members and therefore has an axe to grind, the argument seems indisputable. The cost of widespread monitoring is high, and the propaganda benefit alone may not justify the expense. Alternative methods of persuasion may be more cost effective.

5.5 Audiometry in Courtaulds

The Group factories in Mobile, Alabama, U.S.A. and Calais, France are currently using audiometry in a monitoring role, because it is a legal requirement in those countries, and their experiences will influence the policy of Courtaulds regarding voluntary audiometry in the United Kingdom factories. They, apparently, find the exercise of no significant benefit, and, on the contrary, dismiss it as an expensive nuisance.

The cost of audiometry is the central factor in deciding if, and under what circumstances, audiometry should be introduced to Courtaulds' factories in the United Kingdom. The discussion document on Audiometry in Industry[17] suggests an audiometric programme should be instituted for all those working in a noise environment with an L_{eq} of 105 dB(A) or above. However, routine testing is only considered unnecessary for those whose exposure does not exceed an L_{eq} of 85 dB(A). Between these two levels, into which category a large proportion of Courtaulds' employees must fall, the document merely states that there is an increasing desirability for an audiometry programme as noise levels increase.

If an L_{eq} of 105 dB(A) is chosen as the level below which audiometry is necessary, the number of employees to be screened would be relatively small. It is estimated at a maximum of 500 employees located at 6 sites throughout the United Kingdom. The majority of this number work in noise levels at or about 105 dB(A), so the need for audiometry would be marginal. The processes concerned are weaving, texturising and yarn covering using high speed spindles. If an L_{eq} of 85 dB(A) is chosen, the number of employees would be very much greater, and would be located at more than one hundred sites.

It would not be reasonably practicable to install the audiometric measuring equipment, together with sound proof booths, on any but the largest sites. The estimated cost of an on-site unit is the initial capital of £15,000 There would also be considerable running costs unless the work was undertaken by existing medical staff. The alternative is a mobile unit which would tour the Group sites during the course of a year. A scheme of this kind is operated by Cadbury Schweppes, (Hibbs[20] 1978) covering about 20 of their smaller sites in Great Britain.

The National Association of Drop Forgers and Stampers also have a mobile unit. They are currently purchasing a second mobile unit for £18,000. The units are custom built on a standard chassis. They contain two self recording audiometers, and two sound-proof booths. One trained person operates the unit, and also drives the van from site to site. They have been able to perform a total of 3,000 tests each year, and this they regard as the maximum for one person and one unit since there are also the subsequent audiogram analysis and administrative duties to perform. When travelling expenses and all overheads are included, the estimated cost is currently £4-50 for each examination.

A programme of audiometry in Courtaulds would require similar facilities and incur similar costs. Annual monitoring of all employees exposed to an L_{eq} of

105 dB(A) or more could be achieved with a single mobile unit at a cost to the company of approximately £15,000 a year, which includes the purchase of a mobile unit at £18,000 written-off over five years. It includes the employment of an audiometrician if possible; otherwise a suitable person must be trained. Some medical knowledge is required in order to distinguish other causes of hearing loss from that which is noise-induced. Short training courses are available at Southampton University. It is also necessary for the audiometrician to be qualified and willing to drive the large vehicle.

If screening of all persons exposed to an L_{eq} greater than 85 dB(A) is required, a fleet of at least five such mobile units would be required, in addition to approximately three permanent audiometry units at the largest sites. The total cost to the Group would be of the order of £100,000 a year. If tests were required at a frequency less than once a year, the cost would be less.

There may be a place for audiometry in factories where the noise level exceeds 100 dB(A). It should be an integrated part of a hearing conservation programme, which includes the training of employees in the use of protection. Audiometry alone would largely be a waste of resources, with no real benefit to Courtaulds or the employees. As part of a carefully planned programme it could be of significant benefit, although it would certainly be expensive. In factories where the noise level is less than 100 dB(A) the cost of audiometric monitoring on an annual basis would be enormously expensive. There is an urgent need for funds to be allocated to the fundamentals of hearing conservation, particularly training. When the incidence of high noise levels in the company has been reduced to a minimum, there may be an argument for the widespread use of audiometry in remaining high noise level areas. In the meantime, resources should be concentrated on reducing noise levels where possible, and actively encouraging the use of hearing protection.

6

Pressures on Industry to Reduce Noise Levels

Chapter 6

Pressures on Industry to Reduce Noise Levels

6.1 Introduction

There has been a changing attitude in society during the past decade, which has placed a greater value on a pleasant environment and a safe place to work. It would be naive to imagine this trend will not continue in the future, and we must therefore look at the probable ways in which pressure will be exerted on industry to reduce noise levels. There are two primary sources of motivation: Parliament, through legislation and the Health and Safety Executive, and from the employees themselves. Pressure from the latter will take the form of civil claims for damages where hearing loss has already occurred, or in action by their collective representatives, the unions. The factory manager will also exert pressure on the machine suppliers to reduce the noise emission from their products. The machine manufacturing industry will therefore receive indirect pressure from the same sources, through their customers.

6.2 Legislation

The Health and Safety at Work Act, 1974, is the most obvious single influence on all aspects of health and safety in the past few years. When noise is specifically included in the Act, in the near future, there will undoubtedly be a significantly deeper awareness throughout all industry that action must be taken to reduce noise levels. The wording of the Act, and the importance of the term "reasonably practicable," has been discussed in Chapter 3. The implementation of the Act is as important as the wording of the Act itself, since it gives widespread powers to the Health and Safety Executive, and leaves much to the discretion of the Factory Inspectors.

The power to enter premises, make measurements, photograph, examine machinery, copy documents and interview persons is given to the Factory Inspectors by Section 20 of the Act. They are appointed and controlled by the Health and Safety Executive, a body established by the Act. Discussions with Mr. A. Dove of the Executive gave a valuable insight into the attitude the inspectors are likely to take when regulations for noise are issued. Firstly, they are quite aware of the difficulties faced by managers in many instances in trying to reduce noise levels. They are not going to demand improvements where they are not technically possible, or insist on lower levels where the cost is prohibitive. The philosophy of the Executive is that they can be most effective by maintaining a dialogue with managers, and by offering information and encouragement.

However, the Health and Safety Executive strongly believe that much can be done to reduce noise levels in industry without imposing crippling demands on companies' resources. They are not prepared to allow managers to ignore the hazard to which their employees are subjected. A feasibility study of the possible methods of reducing excessive noise levels is the minimum they will expect, and they will instruct the Factory Inspectorate to use the powers provided by the Health and Safety at Work Act to enforce the strategy. The Act allows Inspectors to serve Improvement Notices and Prohibition Notices. The latter are unlikely to be used in the case of excessive noise, at least in the first instance. Managers can expect to be served with an Improvement Notice if they have employees working in excessive noise levels, in which case they will have a specified period in which to reduce the noise or to show that to do so is not "reasonably practicable." Section 40 of the Act states:

> *40. In any proceedings for an offence under any of the relevant statutory provisions consisting of a failure to comply with a duty or requirement to do something so far as is practicable or so far as is reasonably practicable, or to use the best practicable means to do something, it shall be*

> *for the accused to prove (as the case may be) that it was not practicable or not reasonably practicable to do more than was in fact done to satisfy the duty or requirement, or that there was no better practicable means than was in fact used to satisfy the duty or requirement.*

In the preparation of the section of the draft Group Standard concerned with existing installations (Appendix 1) the recommendation was made that managers of Group factories should make or obtain a written report of the most economical method of reducing noise levels below the target, including the costs involved. If the manager decides on the basis of such evidence that noise control of existing plant is not reasonably practicable, Inspectors are more likely to accept the argument. If the manager dismisses noise control without careful consideration, the Inspectors are much more likely to take action. Managers should also remember a further weapon provided by section two of Health and Safety at Work Act:-

> *2. -(1) It shall be the duty of every employer to ensure, so far as is reasonably practicable, the health, safety and welfare at work of all his employees.*

33.-(1) It is an offence for a person -

(a) to fail to discharge a duty to which he is subject by virtue of sections 2 to 7; ......

6.3 Civil Actions by Employees

There have been a small number of claims brought before the civil court by employees in the Courtaulds Group alleging damage to hearing. In order to be successful the common law requires the claimant to prove the Company has been negligent in allowing the damage to occur. The employee must therefore show that the Company was aware, or should have been aware, that noise levels were sufficiently high to constitute a significant hazard, and that the Company did not take all reasonable steps to prevent the damage occurring. It is important to decide how long the Company should have known of the danger to the hearing of his workforce, and so the approximate date from which he was negligent.

The danger of high noise levels has been common knowledge in some industries, such as boilermaking and dropforging from most of this century, if not longer. Occupational deafness used to be known as "boilermaker's ear." The first attempt to quantify the correlation between hearing loss and noise exposure was in 1954 by the American Standards Association [21]. The first research on the subject in the United Kingdom dates from 1957, initiated by the Department of Scientific and Industrial Research. It is unreasonable to expect most managers to be aware of the correlation until 1963 when the Wilson Report [22] was published. With reference to permanent threshold shift the Wilson Report states:

> *513. It has been established that a permanent reduction of hearing sensitivity can occur in people who are exposed for long periods to noisy environments, such as are found in some industries ...... No appreciable recovery is possible from this condition as the loss of sensitivity of the hearing arises from irreversible damage to delicate parts of the inner ear.*

The Report was published by Her Majesty's Stationery Office. It will be assumed that senior management at Courtaulds would at least have perused the document, particularly since the Chairman of the Committee on the problem of Noise, Sir Alan Wilson, was a past Deputy Chairman of the Main Board of Courtaulds.

In 1972 the Code of Practice for Reducing the Exposure of Employed Persons to Noise [7] was produced It has been widely circulated, and ignorance of the contents will not be accepted as an adequate defence by a Court of Law. In particular the Code of Practice states that where people are exposed to an L_{eq} of 90 dB(A) or more, management should:-

> *3.1.5.* ......
>
> *(c) ensure that suitable ear protectors are provided and are used*
>
> *(d) ensure that people provided with ear protectors are instructed in their care and use, ...*

Employers will be held responsible for all damage to hearing which has occurred since 1972 where employees have been exposed to an L_{eq} greater than 90 dB(A), and hearing protection has not been provided and used. It is insufficient for management to merely provide ear muffs, or to place an ear down dispenser in the foreman's office. In order to comply with the Code of Practice they must ensure the ear protection is used.

6.4 Defence of Civil Actions : A Case History

During the course of this project there have been several discussions between the Engineering Development Department and Group Legal Department. They have covered the general approach to claims for hearing damage, and specific cases for which Engineering Development Department could offer specialist technical advice. As central departments in the Courtaulds Group, both have the function of minimising costs to the Group from civil claims of this sort. There are, at present, only a small number of claims, many of which are settled out of court, some claims are considered unjustified, however, and the possibility of defending the action has to be evaluated.

The following points may be acceptable as a valid defence in certain instances:

1. If audiometric evidence shows no hearing loss beyond that expected from presbycusis.

2. If the claimant has not been working in an L_{eq} of 90 dB(A) or more during his employment with the company.

3. If all reasonable steps have been taken to conform with recommendations in published documents, including ensuring that the

employee used hearing protection if necessary since 1972.

4. An estimated proportion of the total hearing damage, which occurred before knowledge of the noise hazard could reasonably have been expected, (see Section 6.3), may not be liable to compensation.

5. Hearing damage may have been caused by previous employment, by leisure activities such as loud music or shooting firearms, or by non-sensorineural damage perhaps caused by a head injury.

A successful claim for damages must be based on audiometric evidence showing a degree of noise-induced hearing loss. However, a machine operator working in around 90 dB(A) will almost certainly have a measurable hearing loss, although it may not be sufficient for him to be aware of any deficiency. The inclination of the courts at present in cases between an individual and a large company is to award compensation for any degree of hearing loss, however small, providing they consider the company to have been negligent. The amount of compensation depends on the degree of hearing loss, amongst other factors.

Audiometric evidence is therefore unlikely to be of assistance in defence except in special cases, or in reducing the level of the award.

Few parts of the Courtaulds Group could claim to have taken all reasonable steps to protect their employees hearing since 1972 in line with the recommendations of the Code of Practice[7]. Claims by long serving employees may be reduced by arguing that the company was not negligent prior to 1963. Without a pre-employment audiometric test the Courts are unlikely to be sympathetic to arguments that the degree was caused by a previous employment. Evidence of hazardous leisure activities and non-sensorineural damage are likely to assist in reducing levels of compensation, but not in refuting a claim if noise-induced hearing loss has occurred, the working environment is excessively noisy, and the company has been negligent.

Most of the successful claims have been in the high noise level industries such as drop-forging. In the textile industries the machine operators are often exposed to an L_{eq} of only marginally more than 90 dB(A). Although it is well known that a significant hearing hazard exists at an L_{eq} above 80 dB(A). A company could reasonably argue that it had not been negligent if the claimant has been exposed to less than 90 dB(A). This has not been tested in court at present, but it is a line of defence which requires detailed noise measurements, and with which the Engineering Development Department have been able to assist.

A report [23] was prepared on behalf of the Engineering Development Department by myself on the case of an employee, Mr. H., working in one of the acrylic fibre manufacturing plants. Mr. H.'s solicitors have issued a writ for damages due to hearing loss which he claims he has sustained during his employment with Courtaulds. He has been working as a Spinning Auxilliary since 1965. A medical examination has shown he has bilateral senson-neural deafness, with a hearing loss averaged over 1, 2 and 3 kHz of 46 dB in the right ear and 39 dB in the left ear. No audiogram was measured before his employment with Courtaulds. He has sustained two head injuries, and has been an amateur boxer, but the audiogram indicates the hearing loss is noise-induced.

We have to assume that the damage was caused during Mr. H.'s employment with Courtaulds. Noise levels in the acrylic plant are not very high, although sufficiently high to cause damage to the small proportion of the population with sensitive hearing. The exercise of measuring the equivalent continuous noise level to which Mr. H. was exposed was undertaken to attempt to show that the management had not been negligent.

Noise levels were measured with a Bruel and Kjaer Precision Sound Level Meter (type 2203) fitted with a one inch microphone (type 4145.) The meter was held at a height of 1.5 metres, approximately that of a standing operator, and in all positions in which a Spinning Auxilliary normally finds himself during the course of his work. The positions, and the time spent in each position, were obtained from work study data. Appendix 3 contains extracts from the report [23], and shows how the measurements and work study data were combined to estimate the L_{eq}. The 'f' valves in the accompanying Table 21 emphasise the significance of the noise levels on the spin deck in determining the final L_{eq}. For this reason noise levels on the spin deck were more thoroughly measured.

The equivalent continuous noise level to which Mr. H. has been exposed during his employment with Courtaulds is 85 dB(A). There is a significant chance that the exposure could cause the hearing damage exhibited by Mr. H., although the risk is less than 1% (allowing for the effect of age.) A noise level of 85 dB(A) is well within the current recommended maximum, and the Company could justifiably argue that the noise levels in which Mr. H. was required to work did not impose an unreasonable risk. It is therefore unlikely that the Company could be considered negligent.

6.5 Claims from Textile Workers in the Future

The number of claims from Courtaulds' employees is currently very low indeed. In contrast, the drop-forging industry has seen many thousands of claims in the past seven years, almost all of which have been settled out of court. There are cases where every single employee in a drop-forging factory has successfully sued their employer. Undoubtedly, some claimants are receiving compensation they would not be awarded in court, but the insurers and companies generally feel that awards can be kept at a relatively low level if the courts are not given the opportunity to award damages. Experience of other occupational injuries indicates that if a large number of cases come before the courts, the level of award increases rapidly.

The Iron Trades Employers Insurance Association Limited has a number of outstanding claims running into thousands. Damages of up to £27,000 have been awarded, although an average figure is approximately £4,000. There is good reason to believe that the pattern of claims in the drop-forging industry during the past five years will be repeated in the textile industry in the next few years. The drop-forging industry has noted a rapid increase in the number of claims since the Department of Health and Social Security introduced cover for occupational deafness under the Industrial Injuries Scheme in 1975. The qualifications for receiving a pension were very narrowly defined. The minimum hearing loss is 50 dB in the better ear, and only those persons employed for at least 20 years in the drop-forging, casting and shipbuilding industries are included. The limited extent of the scheme was essential to prevent overloading of the National Health Service's audiological services. The Industrial Injuries Advisory Council has recently completed a review of the operation of the occupational deafness scheme, and its report [24] has recently been published. The report recommends a number of changes in the scheme, including extension of occupational cover to those working in textile weaving sheds or on texturing machines. If that recommendation is followed, textile workers in those processes will be informed of the opportunity to obtain the pension by the D.H.S.S., and many will have their hearing examined. When confronted with evidence of hearing loss many can be expected to take civil action against their employer, and the dramatic increase in the number of claims already seen in the drop-forging and similar industries will be repeated in textiles.

The Iron Trades Employers Insurance Association finds that their underwriters require premiums to be loaded for the factories where noise levels are high.

Insurers have to maintain reserves to meet claims in the future.

A typical weaving shed may have a total of 150 operators in three shifts working in noise levels of 100 dB(A). If the normal working week is 40 hours, this is equivalent to an L_{eq} of 100 dB(A). The distribution of degrees of hearing loss is shown in Figure 13. The model assumes the employees are of all ages from 20 to 65 years, and that each has been working in an L_{eq} of 100 dB(A) since the age of 20. In practice, the turnover of labour means that the total number of employees who could sue the company at any one time is considerably greater than 150. Claims are often received from past employees. The number of weavers who would qualify under the Industrial Injuries Scheme would be only 6%. However, claims will be received from employees with considerably less than 50 dB hearing loss. The employer would then have to choose between settling a large number of claims out-of-court, or defending the less justified claims and risk inflating the level of settlements. It has been said that anyone who comes before the court with a demonstrable hearing loss, however small, will receive some compensation.

Whenever the level of hearing loss for successful claims is set, and there is an insufficient body of case law to do this at present, there will be a steady flow of

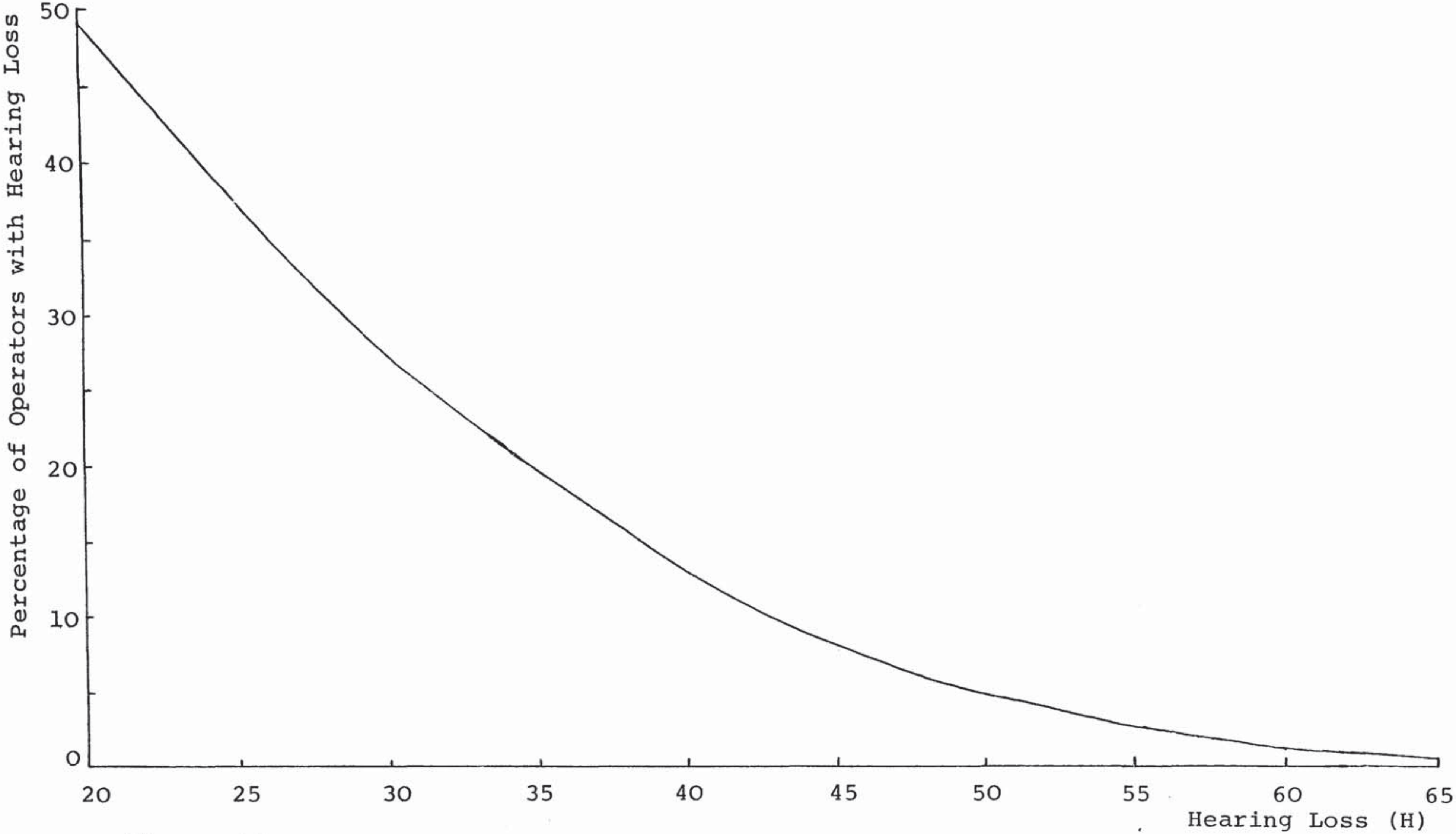


Figure 13 Percentage of Employees Working in 90 dB(A) having a Hearing Loss 'H'

employees moving into this category unless a full and effective hearing conservation programme is introduced. In addition, employees who have already suffered loss of hearing and received compensation will suffer a further deterioration. It is possible for companies to face successive claims from the same workmen, perphaps once every three years. Furthermore, the subsequent claims could be more expensive than the first. In one of the early noise induced deafness claims, Berry-v-Stone Manganese Marine Limited[25] the claimant received half the total compensation for the last three of eleven years exposure because it was considered that each decibel lost was more significant than the last.

The employer of the 150 weavers in the example above could find a total damages bill of £600,000 in the first instance, followed by an annual compensation bill of £100,000, unless hearing conservation is adopted. These estimates assume the level of awards does not dramatically increase between the present and the time when the claims are brought. Some companies in the drop-forging industry have been actively encouraging employees to make claims before inflation hits the level of awards. This practice may have virtue from the companies' view point, providing they are confident they have prevented further hearing loss occurring.

The textile industry therefore faces the likelihood of a large number of claims for hearing damages. The number of employees working in high noise levels in Courtaulds was ascertained as part of this project and using the statistics published by Robinson and Shipton[26], it was possible to estimate the total liability of the Group to hearing loss claims. A substantial wave of claims would be expected initially, and would decline to a steady annual rate unless effective hearing protection is used.

6.6. Unions

The unions can be expected to take an increasingly active role in pressing for lower noise levels. The working party of the Health and Safety Executive have had strong representations from the T.U.C. to enforce a maximum level of 85 dB(A) or lower. However, the unions are aware of the cost of controlling noise and most of the unions' membership would not refuse to work in noisy factories at the expense of their jobs.

The larger unions are organising training courses to inform their officials of the hazards of noise and the steps they should take. Noise will become increasingly evident as a priority in the move towards a better working environment.

7

Environmental Noise

Chapter 7

Environmental Noise

7.1 Introduction

Noise produced by machines in factories can be a nuisance to residents living nearby as well as a hazard to the hearing of those working inside. The levels of noise are naturally much lower, but the level of noise required to cause disturbance is very much less than that which causes damage. The effect of noise on the community has been the subject of extensive research, particularly in relation to noise caused by aircraft, road vehicles and railway trains. The major problem in predicting the degree of disturbance of environmental noise is the subjective nature of the disturbance. People who have lived for many years close to a busy main road are not likely to regard the traffic noise as a nuisance, whereas a new urban motorway is likely to provoke a lot of complaints because it will bring traffic noise into the lives of many people for the first time. The sound of pop music from a night club or youth club would be a hideous disturbance to many, but may be a pleasure to some.

In considering noise as a nuisance, therefore, there are many more factors to be borne in mind than in predicting the risk of damage to hearing. It is true that the intensity of the sound is the biggest single factor in both cases. But for people living near an airport, for example, the number of aircraft which pass in a certain period is also important. The frequency spectrum of the sound produced by the engines varies between aircraft, and some are more disturbing than others. The relative significance of the differing frequencies is not a simple function, as in the case of 'A'-weighting. Then there are the questions of how unwanted the sound is, and how accustomed an individual has become to a certain type of noise, as the illustration of traffic noise shows.

The study of subjective acoustics has led to the development of many scales and units, each trying to accurately quantify the "loudness" or the "noisiness" of the sound as perceived by a typical subject. The loudness level of a sound is the subjective measure of the physical properties of the sound, and is therefore dependant on the intensity, frequency spectrum and durational characteristics heard by the listener. The scale of loudness level, using a unit called a phon, is numerically equal to the sound pressure level (in dB) of a pure tone of 1 kHz which is judged by normal observers to be equally loud. The perceived noisiness of a sound is a measure of the unwantedness of the sound and, as well as including all the conditions relating to loudness level, is also based on criteria of disturbance, unwantedness and objectionableness. The unit is the perceived noise decibel (PNdB), and the scale is such that the perceived noisiness in PNdB is numerically equal to the sound pressure level in dB of an octave band of random noise centred at 1 kHz which is judged by normal observers to be equal in noisiness.

The subjective nature of the scales used to measure environmental noise levels, and the complicated calculations and tests which are associated with using them in practice reflects the unpredictable reaction of humans to the wide range of sounds in the environment. The above is only a summary of the general principals behind subjective acoustics. Fortunately, the disturbance due to the emmission of noise from industrial premises has largely avoided the use of the more esoteric units, and most measurements are made in units of dB(A). In the future L_{eq} could become more common in all fields of environmental noise. Both are easily measured, usually requiring only a direct reading from a sound level meter or statistical analyser.

7.2 Breakout of Noise from Courtaulds' Factories

Complaints from members of the public about disturbance caused by noise from Courtaulds factories are not common, and do not at present constitute a serious problem. Most of the serious complaints, those which involve the local authority, are brought to the attention of the Engineering Development Department, to establish the nature of the claimed nuisance and to advise on the reasonableness of possible remedies. There does not appear to be a rapid expansion in the number of complaints as a result of the Control of Pollution Act 1974[27], which gives wide powers to local authorities to prevent noise disturbance continuing. A greater number of complaints might be expected in view of the fact that many of the mills in the north of England are surrounded by terraces of houses. The reason undoubtedly is the length of time residents and mill have co-existed in these areas. Noise levels have not risen significantly over the decades. People have become accustomed to the noise and are not disturbed by it.

A typical noise complaint was received by a hosiery factory in Belper. Part of the factory overlooks a terraced row of houses, and the residents made complaints to the district council. The council examined the situation and considered the complaints justified. A notice was served under the provisions of the Control of Pollution Act 1974 requiring attenuation of the noise to satisfactory limits. Engineering Development Department were asked to measure the noise levels, to estimate the attenuation required, and to advise on the most economic method of achieving it (reference 28). Examination showed a minimum attenuation of 15 dB was necessary, and that most noise was due to the boiler house and the air conditioning unit.

7.3 A Guide for Managers to the Working of the Control of Pollution Act 1974

Although environmental noise is not a problem which concerns many managers at present, they should be aware of their responsibilities under the Control of Pollution Act 1974. It is particularly important where new developments are taking place, since reducing noise breakout at a later stage is almost invariably more expensive than doing so while the plans are still on the drawing board. The Group Standard on Noise presents an opportunity to circulate all managers with a brief guide to the Control of Pollution 1974 and the attitude of the local authorities. It also makes the Standard complete by including all aspects of noise in industry. However, the section on external noise cannot carry the same force, since action can only be taken when complaints arise, preferably before the local authority becomes involved. A works engineer at the Courtaulds plant in Aintree regularly monitors noise levels outside the site, but only because there have been complaints in the past and the condition of the roof-mounted extractor fans, which cause the noise, does deteriorate over a period of time, with a resulting increase in noise level. Regular monitoring of external noise would not be practicable or necessary for the vast majority of sites.

The section of the Group Standard on Noise covering external noise is reproduced in Appendix 1. The brief introduction reminds the reader that the Standard contains only a summary of the manager's responsibilities and that reference must be made to the Act itself to learn all. This is partly a disclaimer in case, as a result of only reading the Standard, a manager was unaware of certain specific details of the Act and was to put the responsibility for his ignorance on the authors of the Standard.

Complaints from the Public, sub-section 4.1 of the Standard, is almost entirely composed of the fundamentally important sections of the Act as it relates to noise. The use of quotations rather than paraphrasing was in the interest of greater accuracy. Direct quotations also add the weight of authority to the subject, and in restricted quantity do present the necessary information in a form which is easily read. Sections 58-(5) and 72 of the Act are also reproduced to show the manager that the local authorities cannot act unreasonably in insisting on the reduction of noise breakout. Managers often feel they are potentially subject to unlimited demands when local authorities have the backing of legislation of this kind.

It is as well to show them evidence that this is not so, at least in this particular case.

The sub-sections 4.2 and 4.4 of the Standard are discussed in detail in the following two sections respectively. A brief mention of the common sources of noise and the usual method of attenuation is given in sub-section 4.3 of the Standard in the hope that managers may be able to act without requesting outside assistance. Reference will be made in the Appendix of the Standard to detailed sources of recommended methods of attenuation.

Sub-section 4.5 deals with the least significant of the parts concerning noise in the Control of Pollution Act 1974 at present, although potentially the most important. There are just 11 noise abatement zones in operation at July 1978, with a further currently being formed. The purpose of the noise abatement register is to prevent there being an insidious increase in noise levels over a period of time by ensuring they do not at any later stage exceed the level measured for the register. The most important point from the manager's point of view is that it is not in his interests for an uncharacteristically low noise level to be entered on the register. If he is aware of this point he is able to appeal. The prediction of the noise breakout from new developments will be more important in noise abatement zones, with a specific maximum level to meet. The formation of noise abatement zones is likely to be very slow in view of the expense of regularly monitoring noise levels which the project entails.

7.4 Assessing the Existence of a Nuisance

There are many difficulties in measuring environmental noise levels. At large distances from a noise source, of the order of fifty metres or more, the level depends significantly on the direction and strength of the wind. Background noise, particularly from road vehicles, is considerably greater during the day. Most measurements are therefore made at night, which is the time to which most complaints refer.

The measurements are usually made, as was noted in the introduction to this chapter, in units of dB(A). If the noise is steady, or if it fluctuates about a mean which can be estimated by eye, the level is recorded and designated L_s. If periods of louder noise occur, superimposed on the steady level, the higher level is also recorded as L_h. A yardstick is required to assess the probability of the noise level being a nuisance. The British Standard 4142 provides a "Method of Rating Industrial Noise Affecting Mixed Residential and Industrial Areas."[29] The British Standard begins with the measured noise level, and makes corrections according to two factors:-

1. Tonal and impulsive character of the noise.
2. Intermittancy and duration.

For example, if the noise contains a definite whine, or significant bangs, the corrected measured level is 5 dB greater than the measured level. If the sound is produced for only 10% of the duration of the night in total, but has a typical on-time of 2 seconds, 5 dB is deducted from the measured level.

A figure is therefore derived which is an approximation to the "noisiness" of the sound, rather than merely a measure of the physical magnitude of the sound. Even having made these corrections, however, it is necessary to compare the corrected level with a measured background level in order to rate the likelihood of complaint. There is no absolute figure which could be used as an acceptable maximum. Sometimes obtaining a background noise level is not practicable, since to do so requires eliminating the industrial noise and measuring at approximately the same time, the same place, and under similar wind conditions. The British Standard permits a notional background level to be used in place of a measured background level.

The corrected measured noise levels L_s' and L_h' are compared with the measured background level when available, or otherwise the notional background level. In either case BS 4142 states:

> *"Complaints may be expected if either L_s' or L_h' or both exceed the measured background level by 10 dB(A) or more. Differences of 5 dB(A) are of marginal significance. If L_s' and L_h' are more than 10 dB(A) below the ..... background level, this may be taken as a positive indication that complaints should not be expected to arise."*

In practice it has been found by the Engineering Development Department after experience on several external noise measurement exercises, a background noise reading is usually impossible under the conditions defined by BS 4142. A practical alternative which has been used on occasions is to measure the noise level in a similar neighbourhood nearby, where the sound from the factory is inaudible, and where there are no other industrial premises.

The notional background level, the alternative recommended by BS 4142, has not been found to be helpful or accurate. The British Standard uses 50 dB(A) as a starting point, to which corrections are again made. The corrections are based on:-

1. how established the factory is,
2. the type of district, ranging from rural to industrial,
3. the time of day.

For example, an old established mill in which about fifty weaving looms are housed operating continuously would produce a noise outside the mill which has no unpleasant characteristics such as pure tones or impulsive components. The steady noise level at the nearest house may be recorded at night as 55 dB(A) and, since no correction is required,

$$L_s' = 55 \text{ dB(A)}$$

The background level cannot be measured, so BS 4142 allows for the calculation of a notional background level (refer to Appendix A and B of BS 4142):-

Notional level starting point	50 dB(A)
Correction for type of installation *"..... old established factories which are completely in character with the area in which they are situated. ....."*	+ 10
Correction for type of district *"Predominantly residential but with some light industry or main roads."*	+ 10
Correction for time of day *"Night-time, 10 p.m. to 7 a.m."*	- 5
Notional night-time background level	65 dB(A)

The measured noise level of 55 dB(A) is 10 dB less than the notional background level. The British Standard states that if L_s' is more than 10 dB below the notional or measured background level, this may be taken as a positive indication that complaints should not arise. If the background level is measured several streets away, where the mill noise is no longer audible, a typical reading would be 45 dB(A). It is reasonable to assume that were it possible to remove the factory noise and measure at the original position, a measured background level of approximately 45 dB(A) would be recorded. If this were the case, L_s' would exceed the measured background level by 10 dB. The British Standard states that complaints may be expected if L_s' exceeds the measured or notional background level by 10 dB(A) or more.

Experience has shown that the recommendations for calculating a notional background level where necessary are not an accurate alternative. It is recommended in this situation that a background noise level is measured at a position in a similar neighbourhood nearby, but remote from the industrial premises.

7.5 New Developments

The construction of new buildings is an occasion when complaints due to noise are likely to arise, not only as a result of the construction work itself, but also from increased noise breakout from the processes in the new building when complete. The planning stage of a building provides the best opportunity for noise control measures to be taken, since major alterations to structures after completion are often impracticable Local authorities, aware of their responsibilities under the Control of Pollution Act 1974 [27] and the complaints from the public they may receive, are unlikely to grant planning permission for a new construction in a residential area unless they are convinced that complaints will not arise.

The noise from construction work is controlled by section 60 of the Control of Pollution Act 1974. Reference is made to this section, and to the subsequent section in sub-section 8.4 of the Group Standard. Section 61 of the Act allows for agreement to be made in advance with the local authority as to the hours of work and the machinery to be used so that the local authority can be satisfied in advance that no undue nuisance will be caused. No further comment was required in the Group Standard since those undertaking for the construction work can refer to the Act and to the local authority for details. In addition to making managers aware of these sections of the Act, it was also considered useful to point out that a factory manager does not pass all his responsibilities on to a contractor:-

> *60.-(5) A notice under this section shall be served on the person who appears to the local authority*

to be carrying out, or going to carry out, the works, and on such other persons appearing to the local authority to be responsible for, or to have control over, the carrying out of the works as the local authority thinks fit.

The recommendations for the design of new buildings in the Group Standard are brief, since the local authority will normally include detailed limitations on noise break-out in the planning permission. The following case history demonstrates the interaction between local authority and the Company in agreeing noise emission levels for planning permission to be granted. The company, C.H. Fletcher Limited of Steeton, Yorkshire, is a subsidiary of Courtaulds Limited and manufacture furnishing fabrics. As a result of a fire which destroyed part of their premises Fletchers' wished to build an extension to their factory on the existing car park. The extension was to be used initially for storage, although eventually it was hoped that weaving looms would be placed there. The existing buildings have been in their present form since 1953 and are well established, but new housing has recently been built on the opposite side of the narrow road. The relative positions of the buildings and the proposed extension are shown in Figure 14.

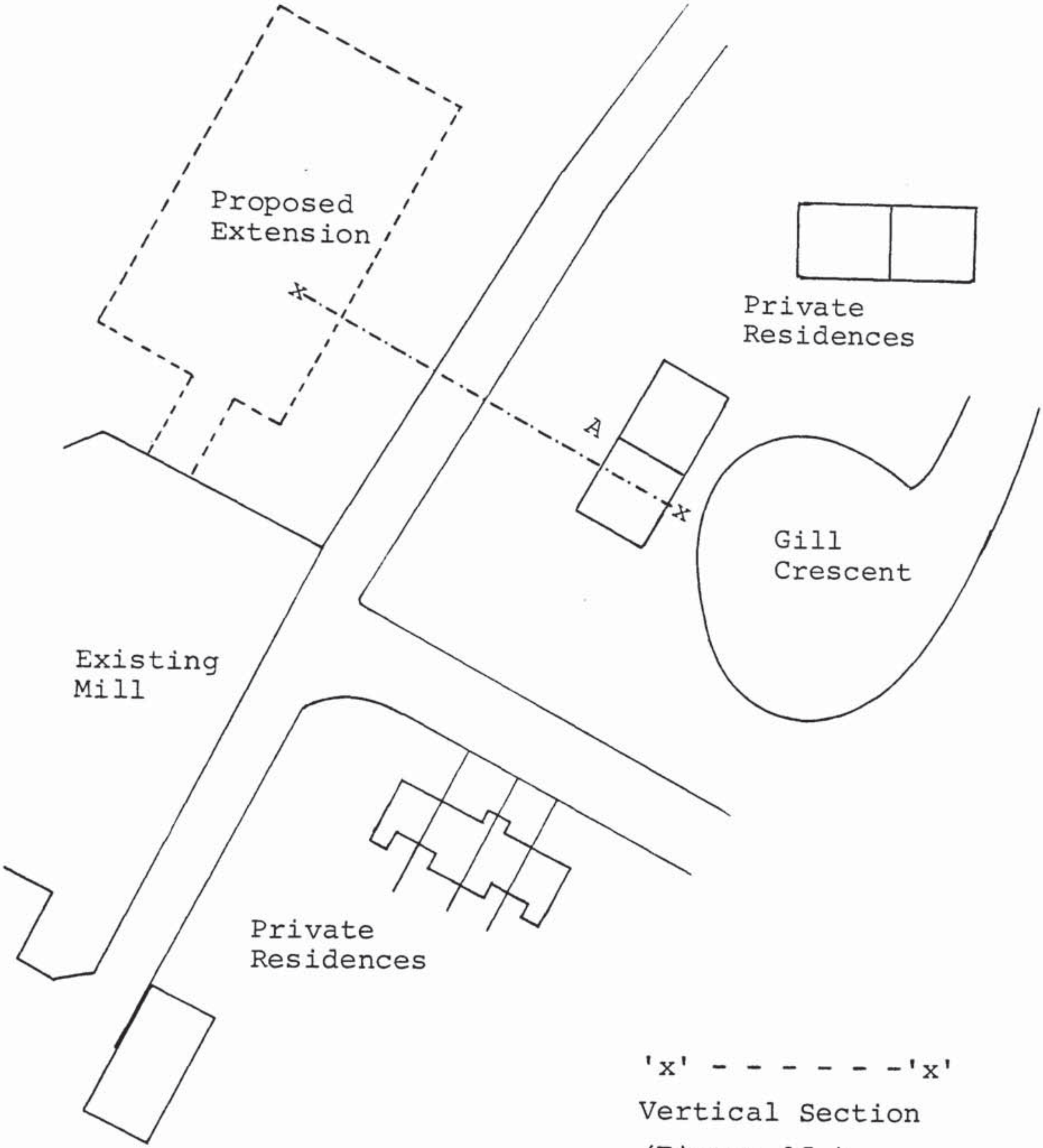


Figure 14

Plan of the Proposed Extension to the C.H. Fletcher Weaving Mill in relation to the Nearest Private Residences

The planning permission was granted by the City of Bradford Metropolitan Council on the 8 July 1976 subject to several conditions including:-

> *"..... before any machinery or plant is installed in the building it shall be soundproofed in order that the noise emission does not exceed a level which shall have previously been approved in writing by the local planning authority."*

Engineering Development Department were asked to advise C.H. Fletcher Limited on the level of noise which would be acceptable, and also on the level of noise breakout which can be expected from the proposed building structure.

The Public Health Department of Bradford Metropolitan Council act as advisers to the planning authority on environmental matters. Their respresentative initially suggested a maximum noise level of 45 dB(A) at the boundary of the factory premises, which he claimed would result in a level of 35 dB(A) at the nearest house. This, it was pointed out, was unrealistic since the noise from the existing weaving shed exceeded this figure without the addition of the new extension. A compromise agreement was that the noise level from the new extension should not cause any measurable increase in the noise level at the nearest house. In order to agree a current noise level, a representative of Public Health Department, the author and a representative of C.H. Fletcher Limited met to make measurements at the position marked 'A' in Figure 15, which was one metre from the house (8 Gill Crescent.) The time of measurement was 11.30 p.m., since the background noise is considerably less at night and the plant, operating 24 hours a day, emits the same noise as during the day. It was a still night, with no wind to interfere with noise measurements.

A level of 43 dB(A) at one metre from the house at 8 Gill Crescent was recorded by both parties, and it was agreed that this would be the maximum noise level at that position after the extension is completed.

The distance between the outside wall of the proposed shed and the position 'A' will result in some attenuation. The attenuation with distance from a plane source of dimensions . 5m by 36m is shown in Figure 15. Within a distance $^a/\pi$, where a is the height, there is a negligible attenuation with distance, since the wall approximates to a plane source of infinite extent. At distances between $^a/\pi$ and $^b/\pi$, where b is the length, the attenuation is 3 dB for each doubling of distance, since the wall is approximately equivalent to a linear

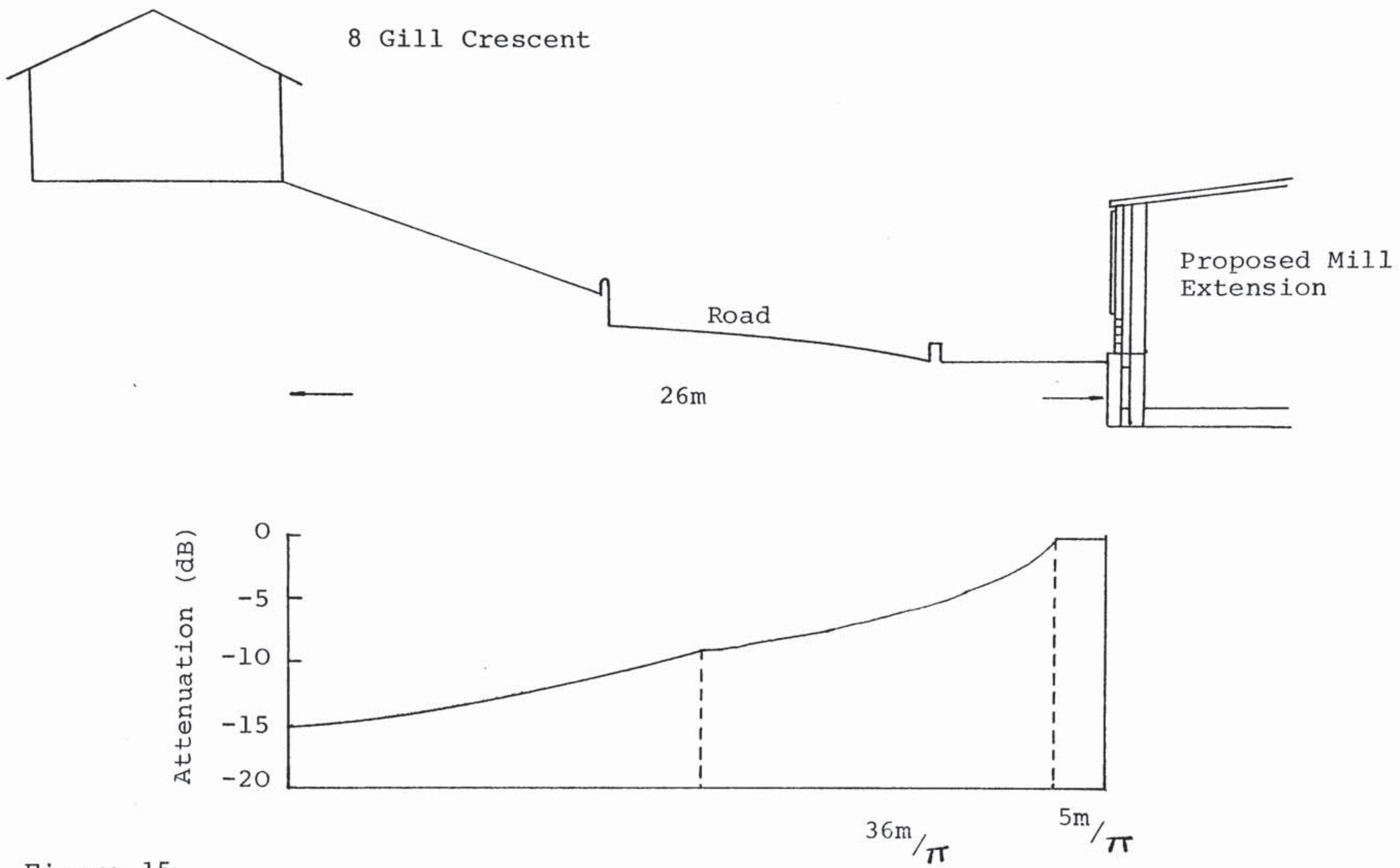


Figure 15

Attenuation with Distance of Sound Radiated from the 36m x 5m Factory Wall source of infinite length. Beyond a distance of $^b/_\Pi$ the attenuation is 6 dB for each doubling of distance, as with a point source. The region of negligible attenuation extends to 1.6m from the wall. Doubling the distance means a 3 dB attenuation at 3.2m, a 6 dB attenuation at 6.4m and a 9 dB attenuation at 12.8m. This is the limit of linear source attenuation. At 26m, the distance of point 'A' the attenuation is approximately a further 6 dB, making a total attenuation due to distance of 15 dB. The noise level at the wall of the new shed (within 1.6m) must therefore not exceed 58 dB(A).

The shed is likely to house 48 Saurer looms which are known to produce noise levels inside the shed of not more than 100 dB(A). An attenuation by the wall of 42 dB is therefore required to meet the agreed standard.

The construction of the west wall is shown in Figure 16 . The lower part is a cavity wall of 100mm thick facing blocks and 100mm breeze blocks separated by 50mm. An attenuation of 50 dB will result from this construction. The upper part of the cavity wall is an exterior sheeting composed of plastic faced pressed metal cladding, and an interior 100mm block work wall lined with glass fibre 50mm thick. An attenuation of 45 dB can be expected from this construction. The roof is to be constructed from three layer roofing felt on 25mm

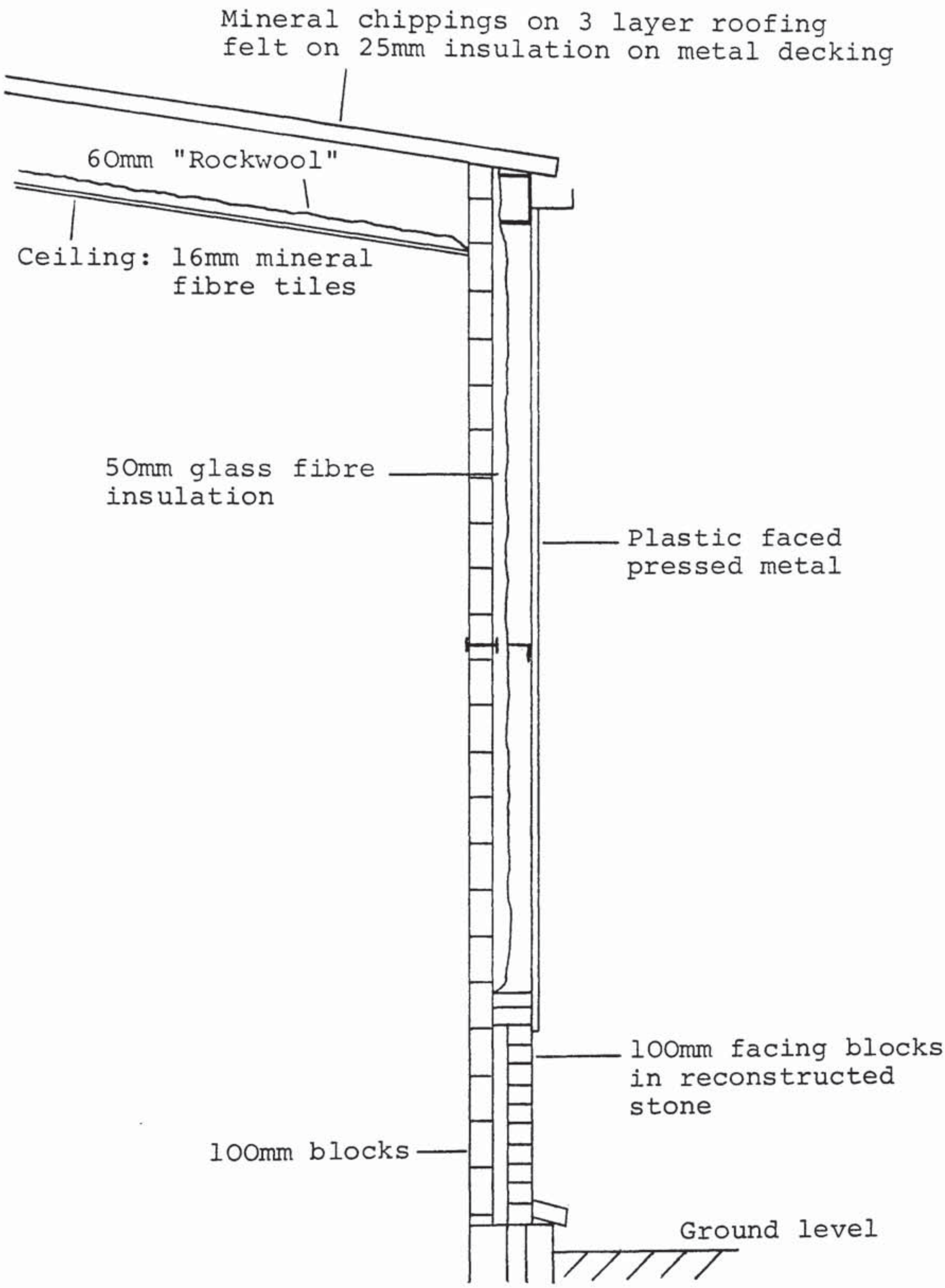


Figure 16

Section through the Wall and Roof of the

Proposed Mill Extension

insulation on metal decking. A suspended ceiling is to hang from the purlins, consisting of 16 mm mineral fibre acoustic tiles with 50 mm rockwool laid above. The attenuation of the ceiling will therefore be 42 dB.

The architectural design was performed by Courtaulds Engineering Limited, who are a subsidiary of Courtaulds Limited in plant construction. They call on Engineering Development Department occasionally to give specialist advice on noise breakout or on predicted noise levels inside factories. We were able to assist by measuring the background noise level, and in specifying the attenuation required by the walls and roof. Equally important, we are able to understand and discuss the question of acceptable and practicable noise breakout levels with local authority representatives to ensure the Company's interests are presented.

8

Noise Sources - The Uptwisting Machine

Chapter 8

Noise Sources - The Uptwisting Machine

8.1 Introduction

At an early stage in the project a Mornington KMT Uptwister was provided by Courtaulds Processing Division for research. The Uptwister is a traditional textile machine which is gradually being superceded by alternative yarn processing methods. An investigation into the causes of noise in Uptwisters was justified on the grounds that control methods may prove to be applicable to many other types of machine. In fact it was known from the beginning that the marginal nature of operating Uptwisters and the continuing reduction in their use meant any recommended modifications would probably not be put into widespread practise.

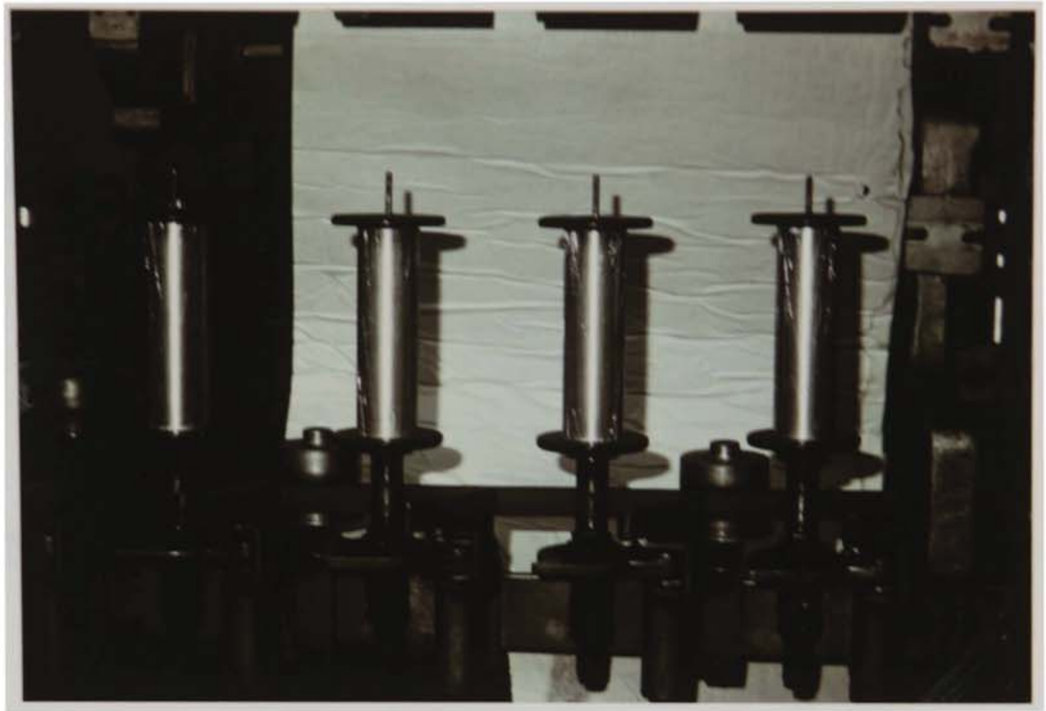
An Uptwister is one of the few textile machines which could be removed from production for a long period and placed in quiet surroundings. Many of them are still well within their operating lifetime, which was an essential condition if meaningful conclusions were to be reached. Otherwise noise due to excessive wear would exceed the noise inherent in the design. The principal purpose of this research was to gain an understanding of the mechanisms by which noise is generated by machines in the textile industry, and to devise general principles for reducing noise levels.

8.2 Description of the KMT Uptwister

Photograph 1 shows a single position of the Uptwister. There are sixty-four identical positions arranged in two decks, and on either side of the machine. For research purposes the length of the machine was reduced to one third of the number of positions which would be found in production.

The function of an Uptwister is to put extra twist into a lightly twisted yarn. At each position yarn is removed from a bobbin held on a spindle, which is rotating at high speed. It passes through a fixed ceramic guide and then through a second ceramic guide which traverses from side to side to wind the yarn onto a cheese. Each position consists of a spindle, two guides and a take-up roller.

The spindles are driven by a flat belt which runs the length of the machine on either side, and round pulleys at either end. Figure 17 shows how the belt passes between rollers on the inside and the spindles on the outside. The latter are held in position against the belt by springs, and one idler between each alternate spindle is necessary to ensure good contact. A 10 H.P.



Photograph 1

Single Position of a KMT Uptwister

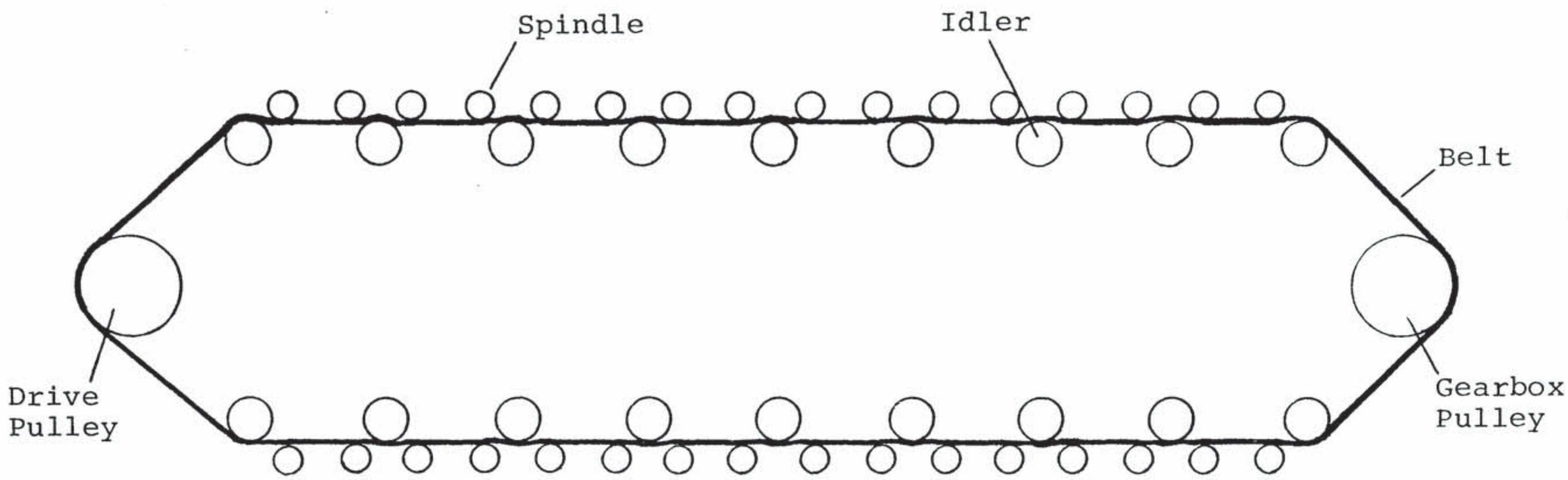


Figure 17

Drive Belt Path in Uptwister

motor drives the belt via the pulley at one end. At the other end the pulley drives the traverse and take-up mechanisms through a reduction gearbox. The position of the motor can be adjusted to vary the tension in the belt.

The two decks of the Uptwister are identical, with two motors, two belts and two gearboxes to each machine. Only the upper deck of the test machine was used in the experiments described here. Relevant machine parameters are recorded in Table 15, since they recur in the experimental descriptions. The motor speed cannot be altered, and the spindle speed could only have been changed by machining a drive pulley of a different size.

8.3 Separation of Component Contributions

By removing the belt, or by using it to drive only parts of the machine, it is possible to determine the noise produced by individual components. The noise generating components are classified into the following groups:-

(i) Motor

(ii) Traverse : take-up and traverse mechanism, plus gearbox

(iii) Idlers

(iv) Spindles and Belt

Spindle Speed	8160 r.p.m. (136Hz)
Idler Speed	2900 r.p.m. (48Hz)
Belt Speed	838 m/min. or 92 r.p.m.
Drive Motor Pulley	2675 r.p.m.
Take-Up Speed	7.47 m/min.
Belt Length	8.94 m
Inter-Spindle Distance	200 mm
Drive Pulley Circumference	165 mm

Table 15

Relevant Dimensions and Speeds of the Uptwister

Noise levels can be measured with the machine in any one of the following states:-

a) Remove belt completely - motor running without load

b) Allow belt to pass round the motor and pulley only

c) Pass the belt in and out of the roller pulleys, so they are all driven, but with the spindles not in contact with the belt

d) The machine running as normal

Sound intensity level, referring to a hearing threshold intensity of $10^{-12}\ wm^{-2}$, is numerically equal to the sound pressure level. Sound intensity levels can be combined according to the Principle of Superposition of Energy, so that for two noise sources l_1 and l_2 the total noise level is L, where:

$$10^{L/10} = 10^{l_1/10} + 10^{l_2/10}$$

Rearranging this equation for a known L and l_1 enables l_2 to be found:

$$l_2 = 10 \log_{10} (10^{L/10} - 10^{l_1/10})$$

Using such a process of logarithmic subtraction an estimate of the four component noise levels can be made.

(i) Motor

This is obtained directly from measurement (a). There was some error due to the motor being under zero load conditions.

(ii) Take-Up, Traverse and Gearbox

Measurement (b) less measurement (a). A slight error will have been caused by noise from the belt as it passed down the centre of the machine and was liable to flap, or to touch cross members. The tension was very low, and so the belt did not vibrate and was unlikely to have generated significant noise.

(iii) Idlers (and Belt)

Measurement (c) less measurement (b). The belt had to be passed in and out of the idlers to maintain contact, so the direction of loading was increased on half of the idlers, and the contact angle was greater on all of them. The error from this cause was not significant since increasing the belt tension did not increase the noise level, implying that the force on the idler is not an important factor in determining the noise generated. Note that the calculated noise level includes the noise produced by the contact between belt and idler, and from the belt itself.

(iv) Spindles and Belt

Measurement (d) less measurement (c). The noise caused by the belt in this case differs from that in (iii) since the excitation forces are different.

The 'A'-weighted noise level and octave band frequency analysis were measured using a precision sound level meter with octave band filter set at three positions along the Uptwister. The instrument was held at a height of 1.2m, and at a distance of 1m from the machine with the 1 inch microphone directed towards it. The three positions were named x, y and z.

x) Nearest the spindle adjacent to the gearbox gearbox end.
y) Midway along the machine.
z) Nearest the spindle adjacent to the motor end.

State of Machine (see text)	Measuring Position		
	x	y	z
a	50.5	54.5	59.5
b	69.5	69.8	67.9
c	73.9	76.2	76.0
d	82.8	84.7	82.5

Table 16

Measured Noise Levels (in dB(A)) at Three Positions (x, y, z)

	Component Group	Derived from:	Noise Level (dB(A))		
			x	y	z
(i)	Motor	a	50.5	54.5	59.5
(ii)	Traverse	b - a	69.4	69.7	67.2
(iii)	Idlers	c - b	71.9	75.1	75.3
(iv)	Spindles + Belt	d - c	82.2	84.0	81.4

Table 17

Separated Component Noise Levels

The measured 'A'-weighted noise levels are shown in Table 16. The noise levels attributable to the component groups (i), (ii), (iii) and (iv) were calculated and are shown in Table 17. The results are repeated in the form of a histogram in Figure 18 where they can be compared with the total noise levels in the three measuring positions. The octave band levels of the noise at the three positions were averaged for each band, and the resulting mean octave band analysis for each component group is shown in Figure 19.

The measurements confirmed that the motor and traverse do not have a significant influence on the overall noise level. The idlers were also found to be relatively quiet, with a contribution at least 6dB less than the spindles and belt. A higher level might have been expected since the idlers are highly reverberant if struck by a metal object. However, they are rotating at about one third the speed of the spindles, and the contact with the belt certainly damps the reverberations considerably.

The spindle and belt combination are the chief sources only increasing the level by a mean of less than 1dB. This technique is not suitable for further analysis of the separate noise sources within the belt spindle system, since the spindles cannot be run without the belt,

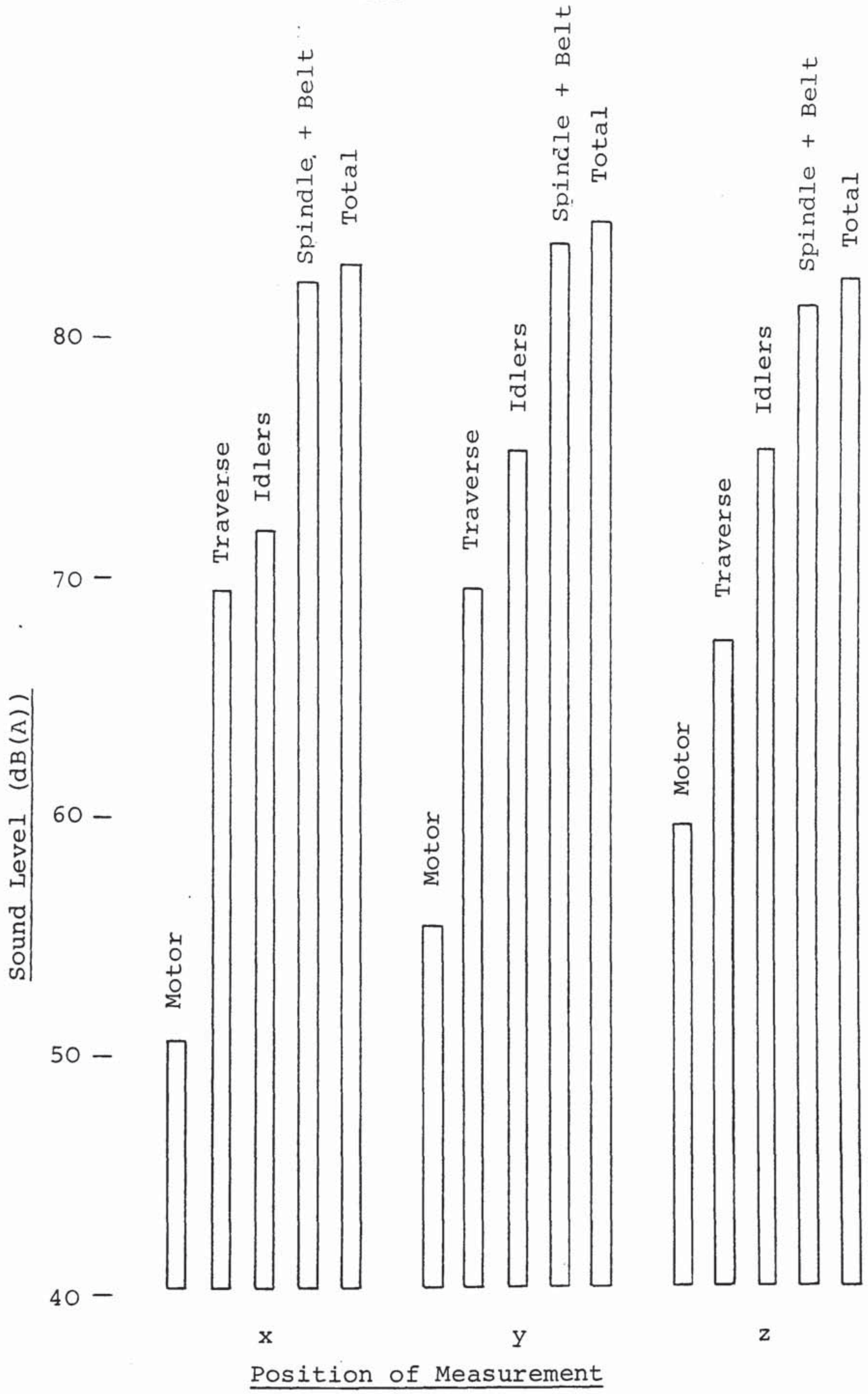


Figure 18

Separation of Noise Source Components in the Uptwister

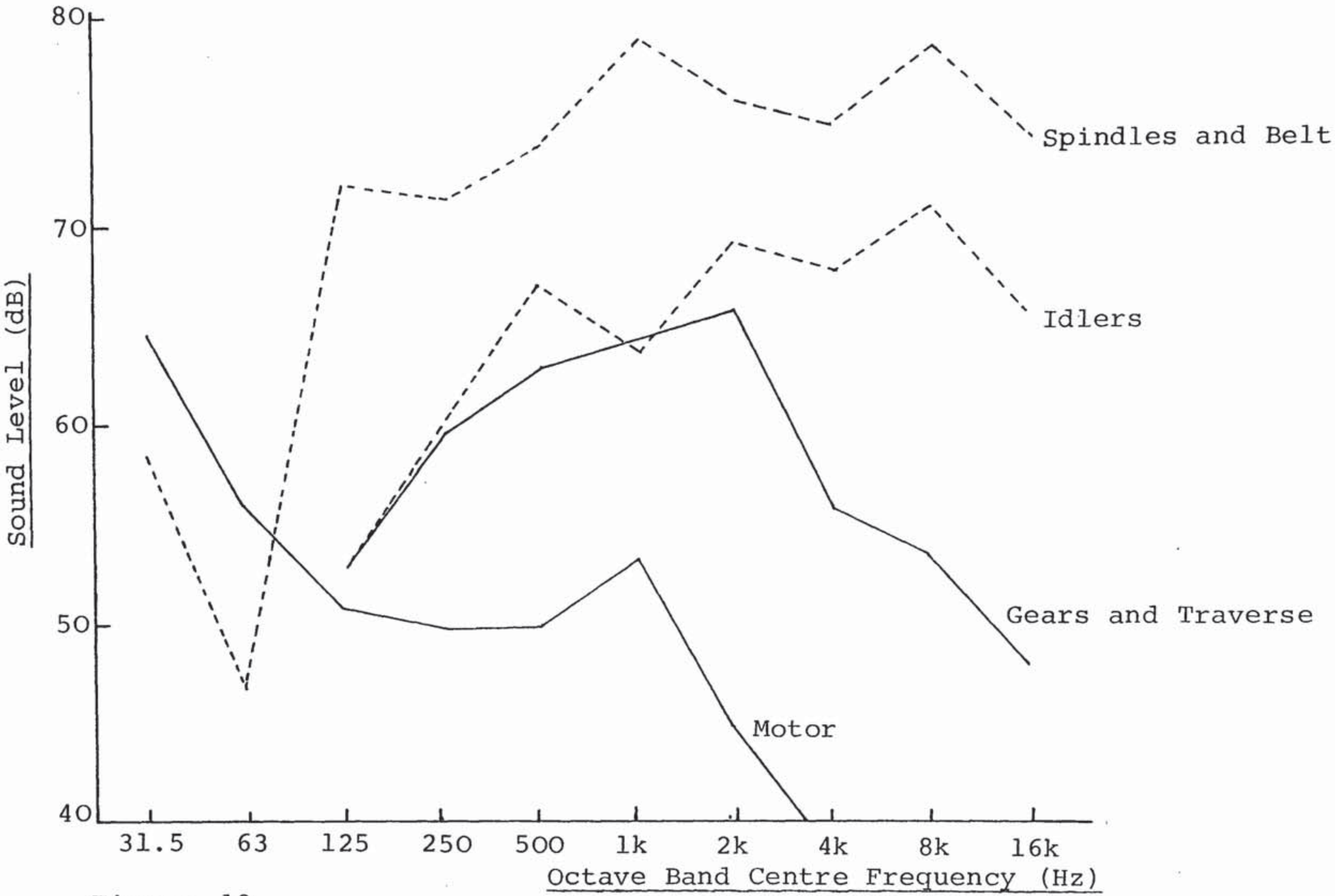


Figure 19

Separation of Components - Octave Band Analysis and the belt is not producing the same noise when it is out of contact with the spindles.

8.4 Noise from the Spindles and Belt

Further investigation of the area from which most is emitted upset the long held assumption amongst Courtaulds designers that most noise from machines of this kind is windage from the surface of the spindle and bobbin. The technique used was to mount a ½ inch microphone close to the uptwister and to make sound level measurements at different points on a plane parallel to the machine. With the microphone directed towards the machine, and at sufficiently small distances, the measured sound level is closely related to the noise emitted by the machine from the area closest to the microphone.

The results of this experiment indicated that the belt, rather than the bobbins, was responsible for most of the radiated noise. The construction of the uptwister spindle assembly is shown in Figure 20. The spindle bearings were found to be relatively quiet, except in a few cases where the bearings were worn. In addition, results showed that yarn on the bobbin had no significant effect.

In order to ensure an accurate positioning of the

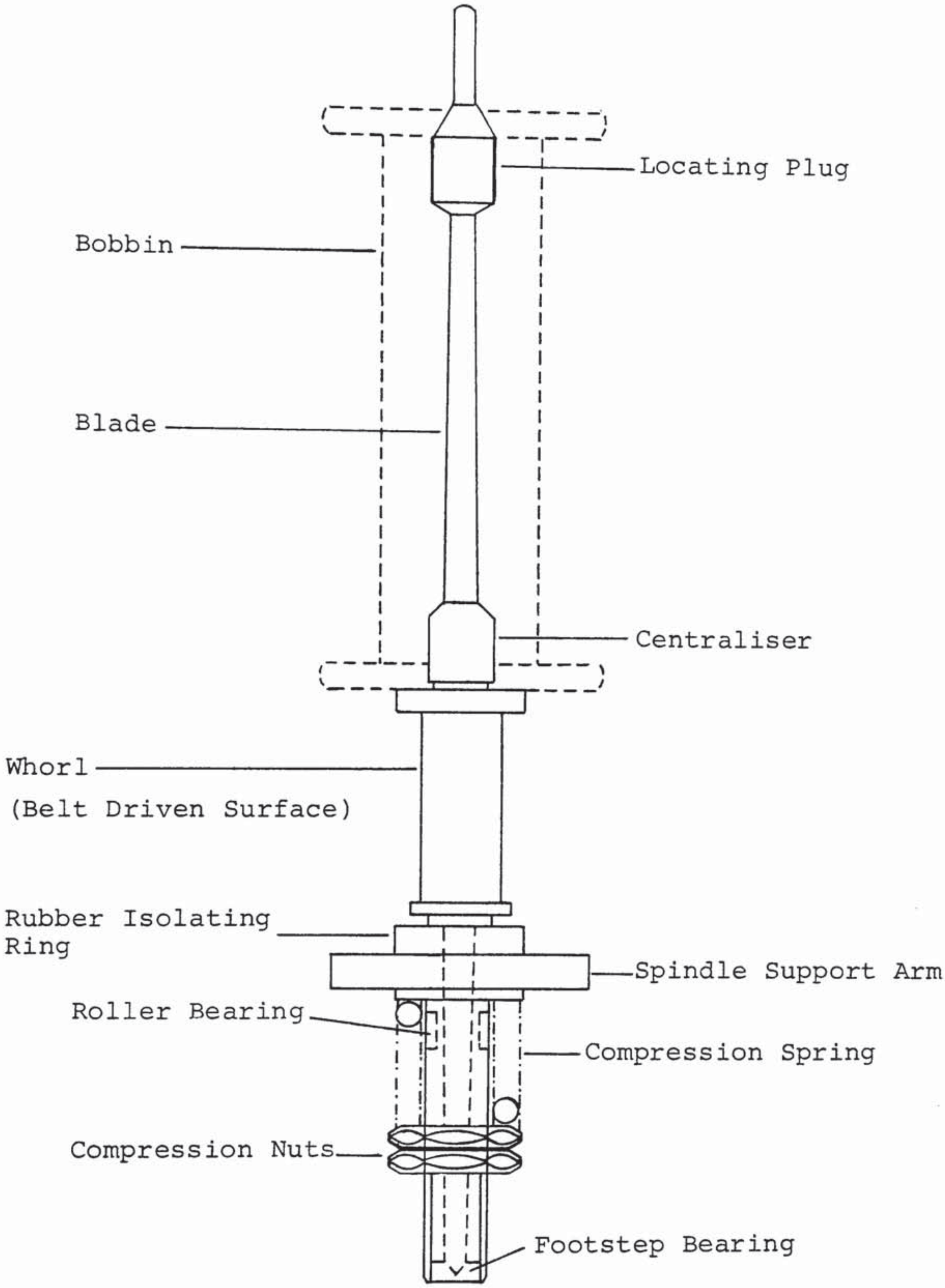


Figure 20

Diagram of an Uptwister Spindle

microphone and a constant displacement between measuring points, a grid was constructed on a temporary framework. The area of the grid covered two machine positions, that is two spindles, and the full height of the bobbin and bearing. The grid, made of tightly stretched strings, was composed of 40 mm. squares arranged sixteen across and twelve high.

The most accurate measurements would be expected with the microphone positioned as close as possible to the machine. If the microphone were placed too close to the surface of the machine reverberations resulting in standing waves would be set up between the surface and the microphone diaphragm. In addition, the sound field close to an extended radiating surface is often very complex and subject to substantial variation with distance. This is the "Near Field" zone.

The variation in measured sound level with the distance of the microphone from the machine was determined for distances between 25mm and 450mm. The microphone was directed at the central part of an empty bobbin surface. The recorded measurements are shown in Figure 21. At a distance of less than 50mm there is a rapid decrease in sound level with distance. The accuracy of measurements as close as 50mm to the machine would be severely limited by the accuracy of setting the microphone in position.

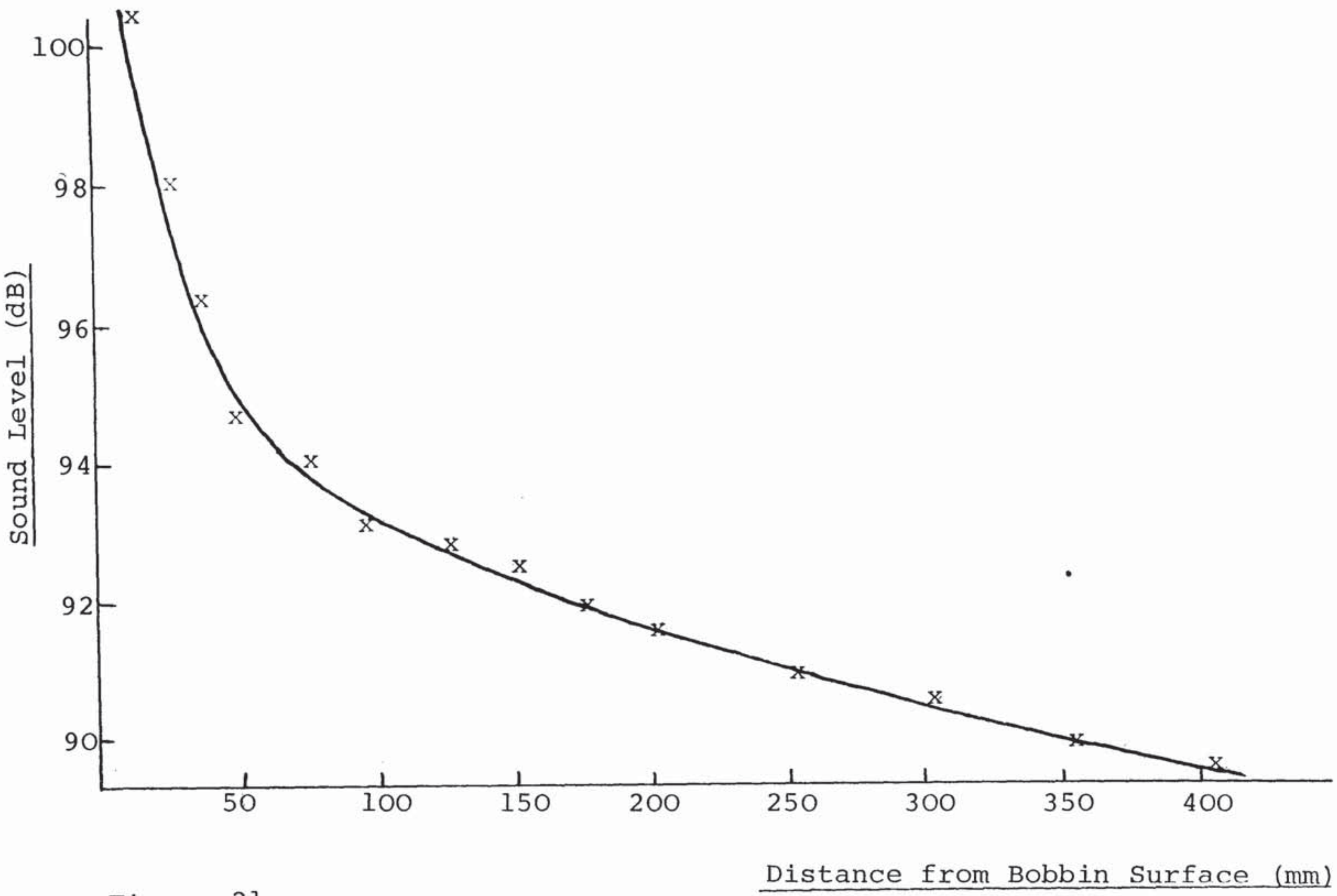


Figure 21

Effect of Reverberation between the Noise Radiating Bobbin Surface and the Diaphragm of the Microphone for varying separation

Beyond about 100mm the level decreases by between 1.5dB and 2.0dB for each doubling of distance, which is consistent with that expected for an extended source which is not uniform and not exactly planar. A distance of 120mm was chosen as the closest which could safely be used to avoid distortion.

The objective was to make measurements which were related as closely as possible to the sound the operator would hear at considerably greater distances from the machine. For this reason the 'A'-weighted sound pressure level was measured throughout this experiment. Although inaccuracies can be caused where low frequency airbourne noise excites another part of the machine and secondary radiation takes place with high harmonics, most of the noise from these machines is direct field. Units of dB(A) were therefore chosen in preference to unweighted decibels.

The effect of the frame on sound level measurements was ascertained. After a series of four measurements with the frame in place and four with it removed the mean levels were:-

Frame in place 95.8 dB(A) (standard deviation 0.4)
Frame removed 95.2 dB(A) (standard deviation 0.4)

The systematic error introduced by the frame of 0.6 dB is comparable with the random error, 0.4dB, caused by repositioning the microphone. The effect of the frame was therefore neglected and the error in measuring sound levels at the frame assumed to be approximately $\pm$ 0.5dB.

Noise levels were measured at each square of the grid first with empty bobbins on the spindles. The exercise was then repeated with full bobbins and finally with the spindles bare. The individual noise measurements were used to construct contour diagrams of 'A'-weighted sound levels, and are shown in Figures 22-24. Points of equal sound level are joined by a line which is labelled in the Figures with the appropriate sound level. The pattern of sound contours produced closely indicates the positions of maximum noise at the grid.

In all cases the predominant noise source is clearly at the level of the belt and the driven part of the spindle known as the whorl. The horizontal nature of the contour pattern suggests a horizontally extended noise source which rules out the upper part of the spindle, and the bobbin as major noise sources. The sound level attenuates rapidly below the belt level as well as above, indicating the noise from the bearings is less important to the overall noise level than the area of the belt. Each of the three cases show a "high spot" on the left hand spindle. The variation in noise level generated by different spindles is a common feature of the Uptwister.

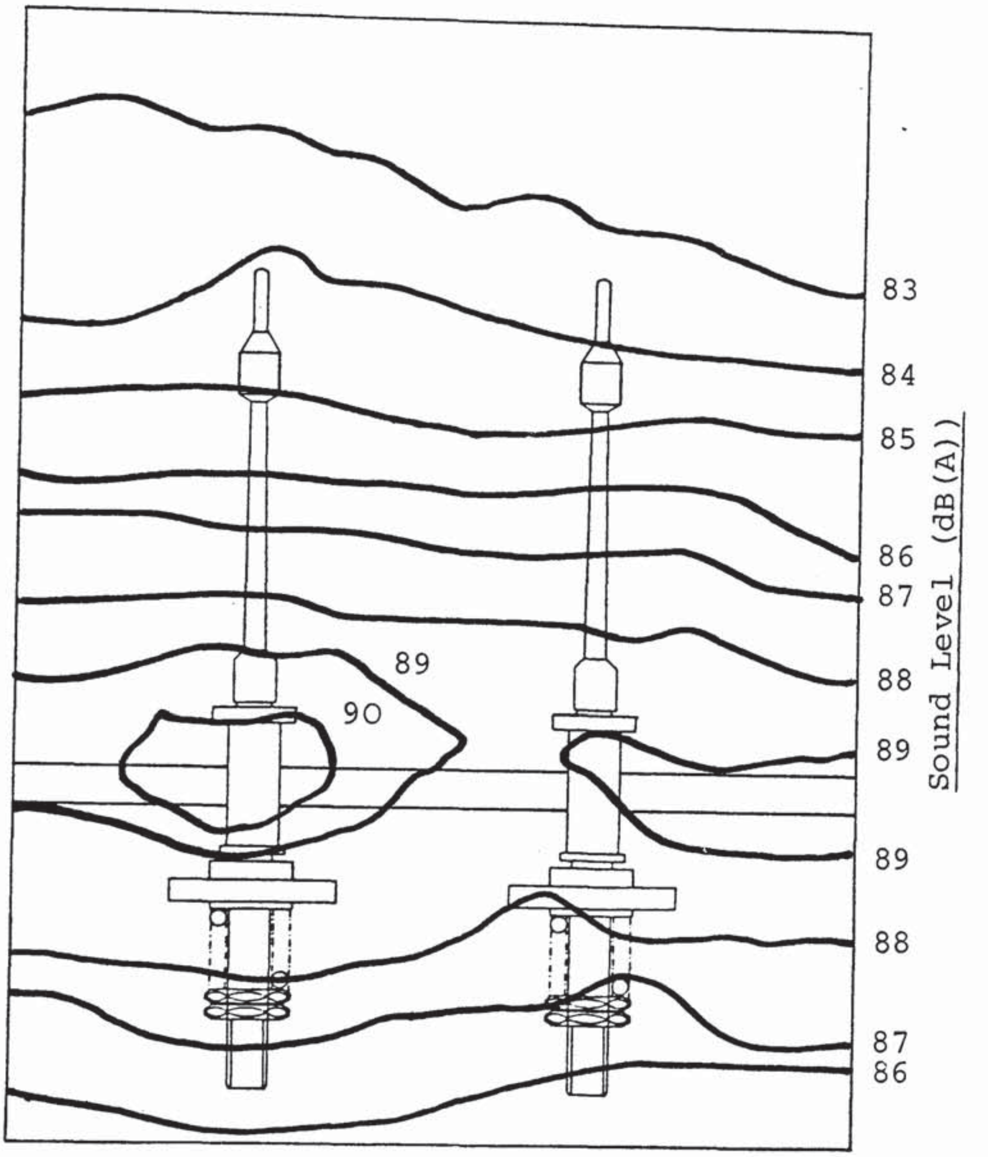


Figure 22

Noise Contours of the Spindle-Belt System in the Uptwister - with No Bobbins

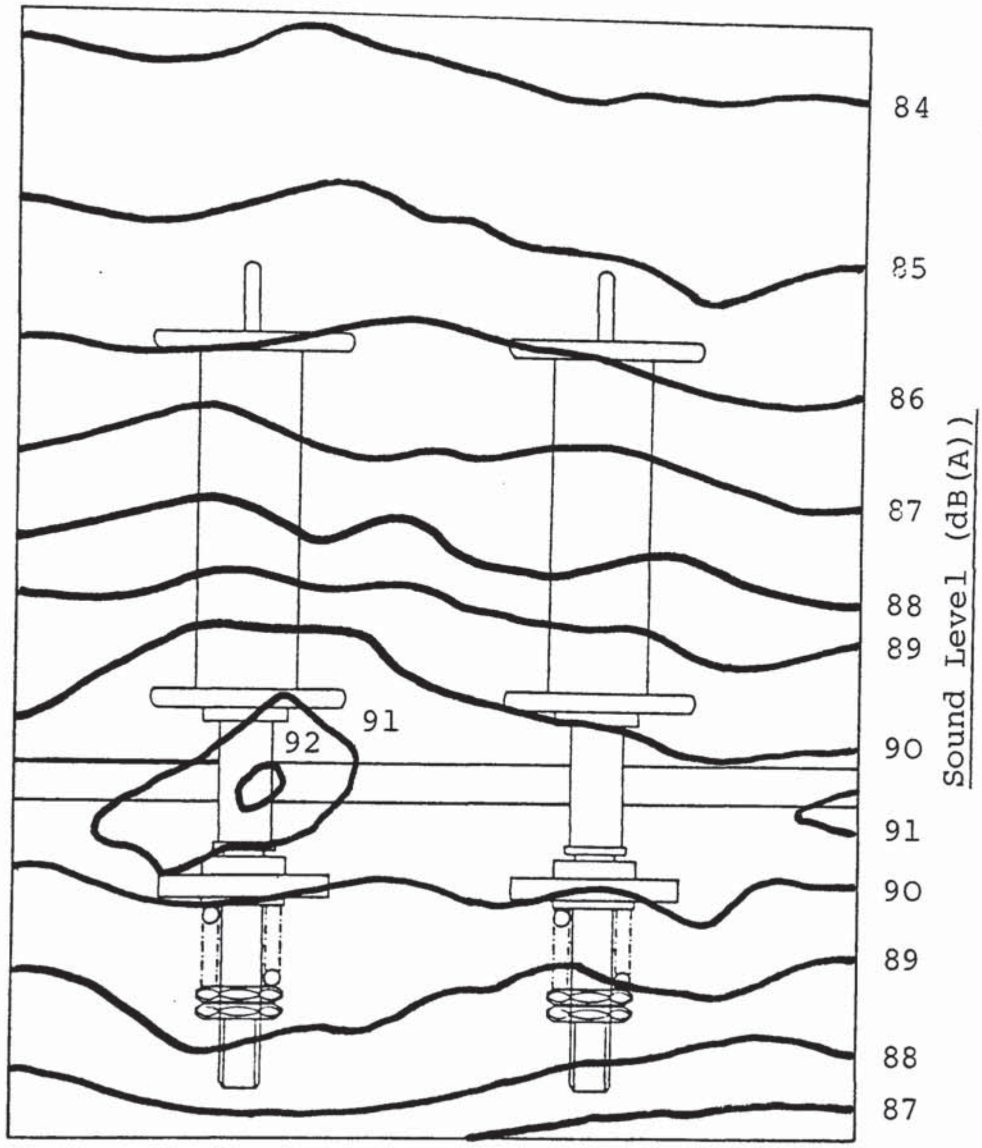


Figure 23

Noise Contours of the Spindle-Belt System in the Uptwister - with Empty Bobbins

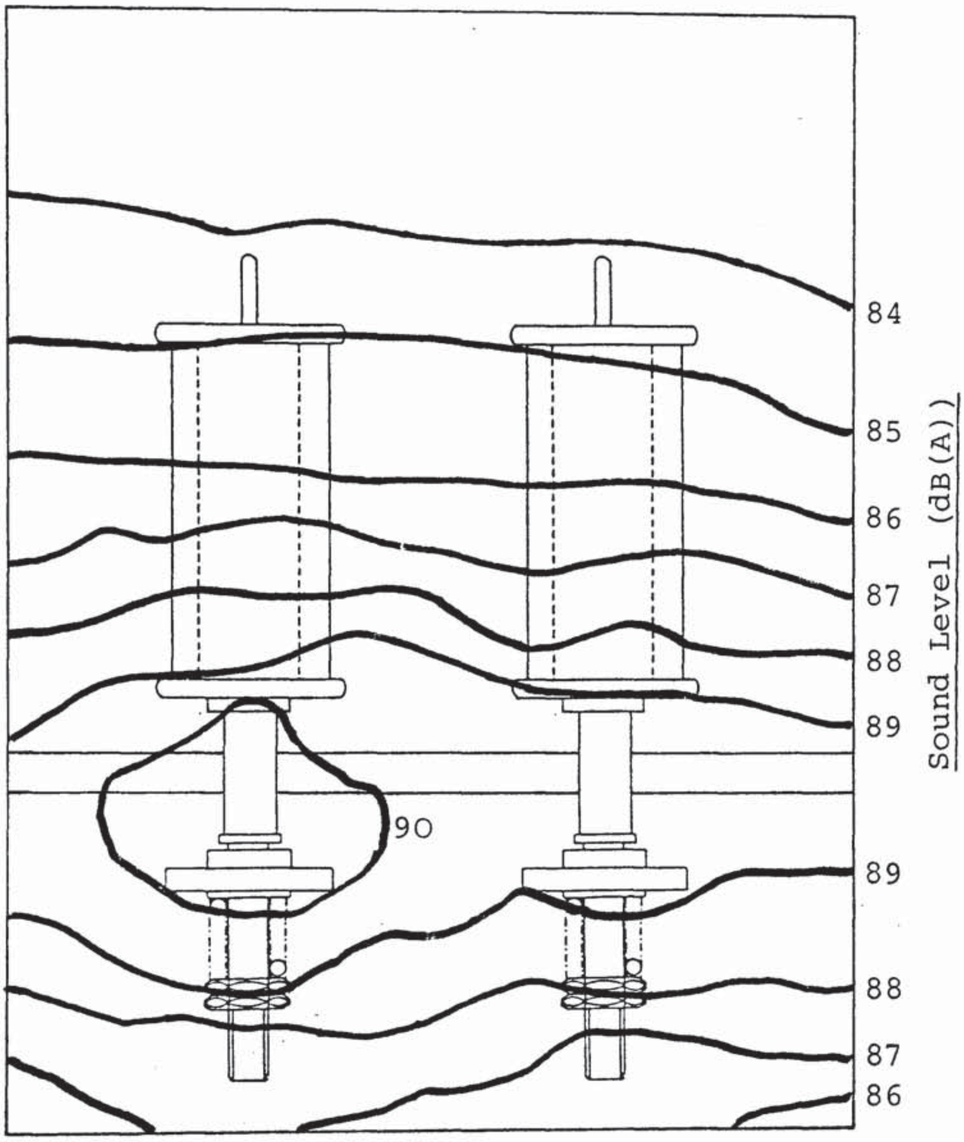


Figure 24

Noise Contours of the Spindle-Belt System

in the Uptwister - with Full Bobbins

The absolute noise level measurements shown by the contours in Figures 22-24, should not be used for comparison purposes since each time the machine was stopped to remove or replace a bobbin the noise levels changed slightly. However, the pattern of the contours was very reproduceable and can be used instead of absolute sound levels to compare spindle loads.

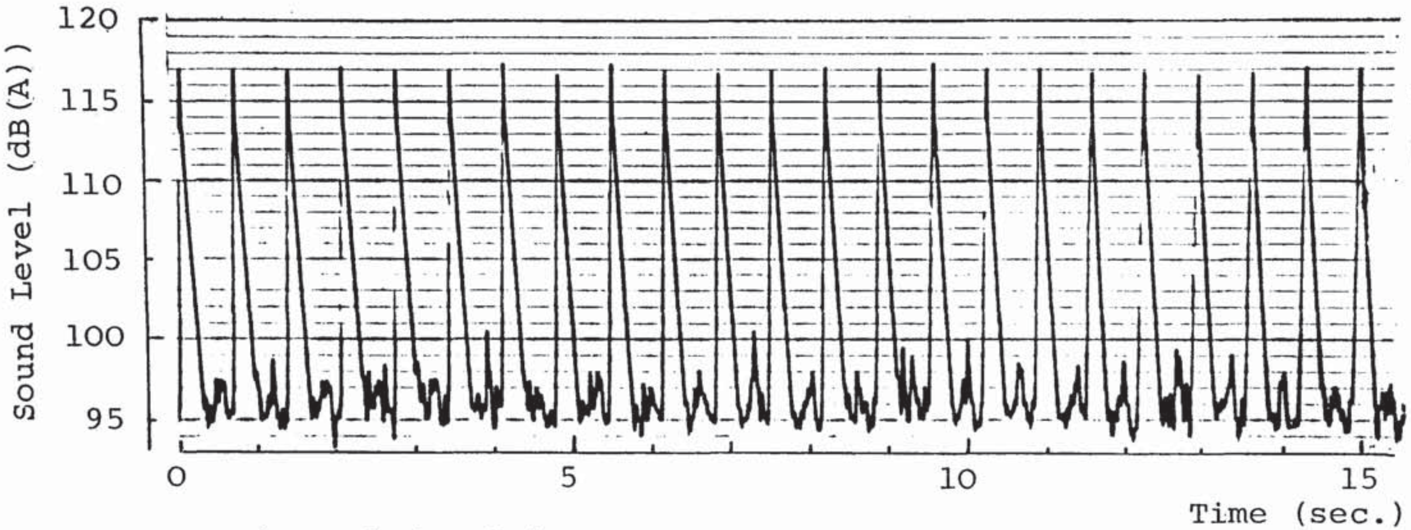
The attenuation of sound level between the maximum at the belt and the top of spindle is 5dB in the two cases where a bobbin was in place on the spindle, and 6dB where one was not. This minor difference suggests that the surface of the bobbin, with or without a covering of yarn, does not radiate significant noise. Further evidence is provided by the contour lines above the top of the bobbins. If the bobbins were radiating significantly a sharp attenuation would be found above the level of the top of the bobbins, with contour lines closer together. This was not found to be the case.

8.5 Noise from the Joint in the Belt

The flat belt drive on the Uptwister under test had been joined to form a loop. The passage of the joint past each spindle and idler caused an impulsive sound. Some production machines use continuous belts without a joint, although many were still using jointed belts. As well as drawing the obvious conclusion that noise levels can be reduced in the Uptwisting areas of the production plant by using continuous belts, the result of investigating the effect of the joint was to discover some interesting properties of flat belts.

A Bruel and Kjaer Frequency Analyser (type 2120) was used as a linear amplifier without filters for measurement of the impulsive sound from the joint in the belt because the Analyser has the facility of variable time constant damping. The damped signal from the microphone was converted to a d.c. signal and recorded on a Level Recorder (type 2307.)

Peak sound levels of 117 dB(A) were recorded with the "+ peak" setting of the Analyser and are shown in Figure 25. This is the minimum peak level, since the rise time of the recorded trace is of the order of 0.1 second. For the duration of the impulse measurements all but one spindle was removed, and the microphone placed close to the single spindle. The period between peaks in Figure 25 corresponds to the frequency of passage of the joint in the belt, 0.65 second. During the period of a single rotation by the belt, the joint must pass 32 spindles. The recorded rise time of approximately 0.1 second is therefore likely to be considerably longer than the rise time of the sound level and therefore a result mainly of



(+ peak levels)

Figure 25

Impulsive Sound Resulting from the Passage of the

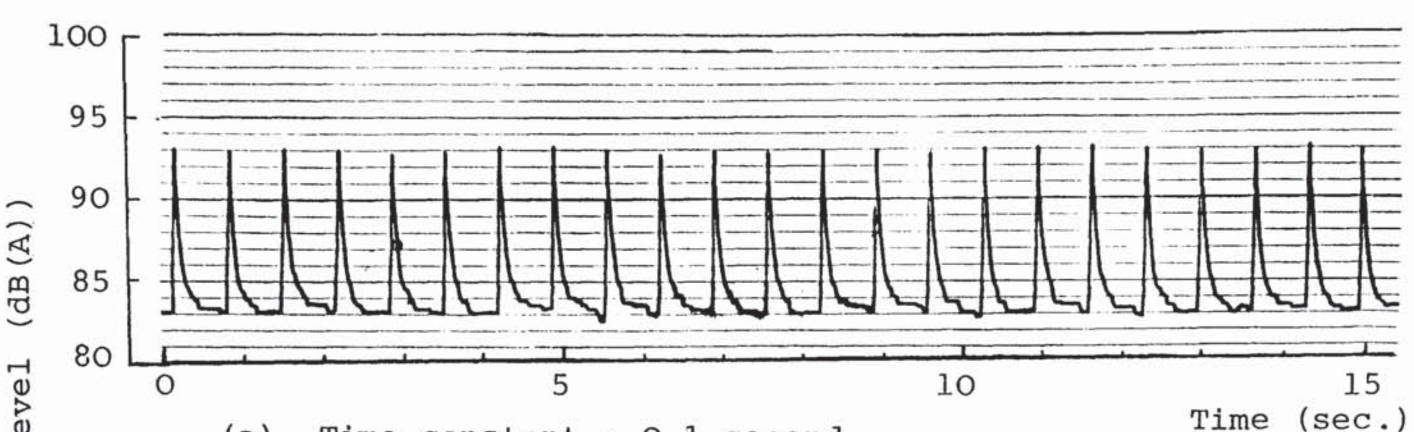
Belt Joint past a Single Spindle

the instrumentation.

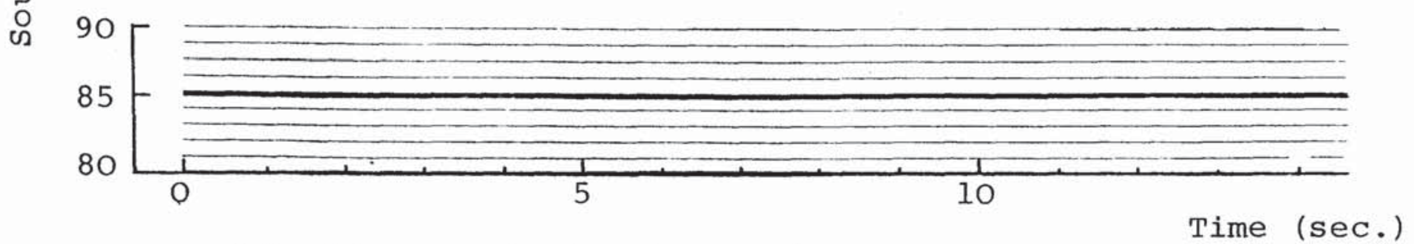
The trace shown in Figure 26(a) is the RMS 'A'-weighted level with the averaging network on the analyser set at 0.1 second. The microphone was held at a height of 1.2m and directed towards the single driven spindle at a distance of 0.2m. The sound generated by the impulsive shock of the joint is assumed to have decayed to zero after 0.65 seconds, so the mean minimum level recorded is 83 dB(A). This would be the constant noise level if there were no joint in the belt. By increasing the averaging time from 0.1 second to a period very long compared to the time between impulses the equivalent continuous noise level was obtained. Figure 26(b) shows the recorded level of 85 dB(A) made with an averaging time of 3 seconds. The joint in the belt increases the noise level by an equivalent of 2 dB. The improvement would be expected for each spindle, and therefore replacing all jointed belts in a Uptwisting area by jointless belts would reduce levels by 2 dB.

8.6 Radiation of Belt Noise

The contour measurements discussed above indicate the noise is radiated in the belt spindle assembly. The impulsive noise generated by the joint in the belt is just one noise source, but by determining from where the impulse



(a) Time constant : 0.1 second



(b) Time constant : 3 seconds

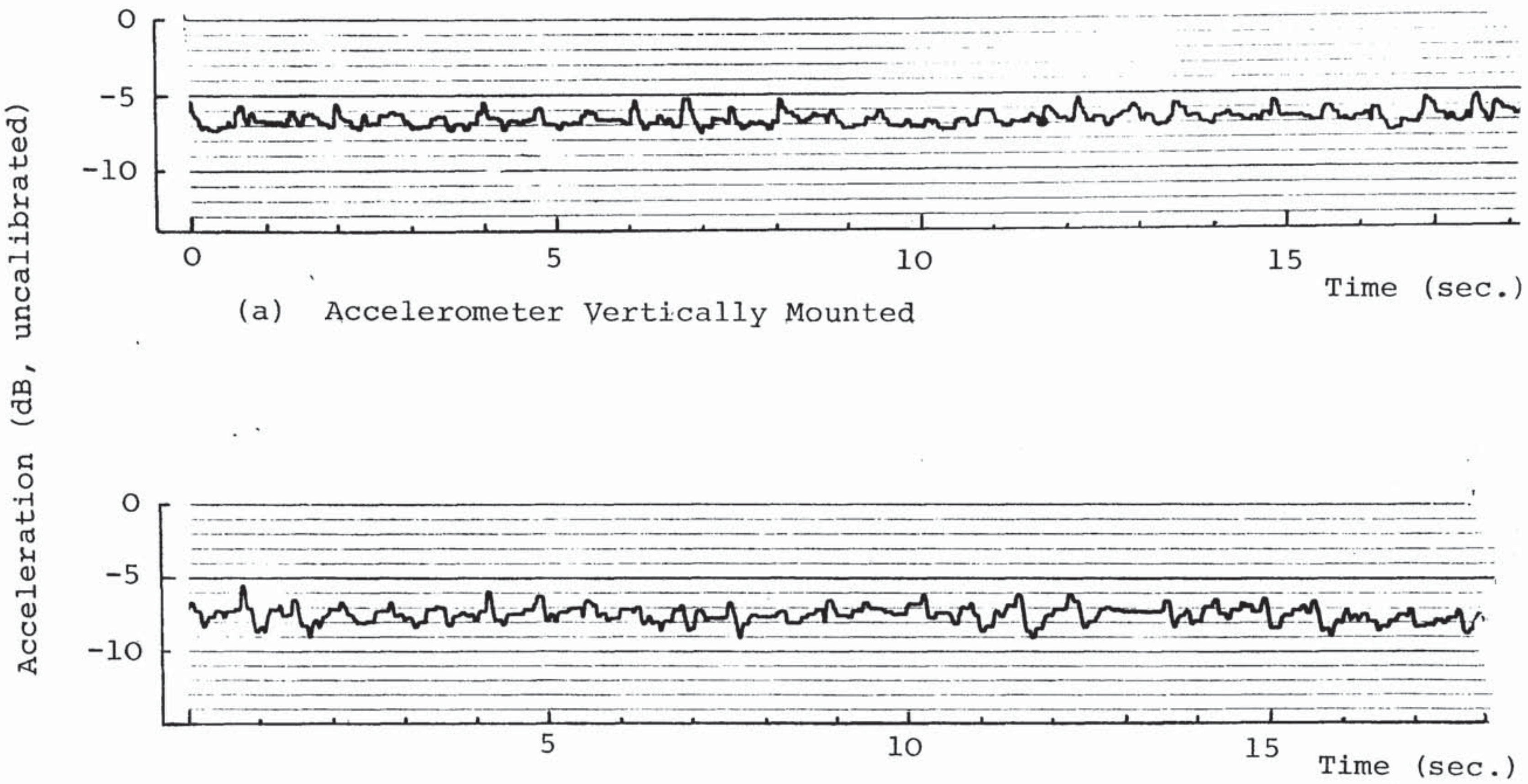
Figure 26

RMS Sound Levels resulting from the Passage of the Belt Joint past a Single Spindle noise is radiated, the mechanism of noise transmission can be found.

The two alternative radiating surfaces are the belt and the spindle assembly. By mounting a transducer vertically on the spindle support and recording the signal as a function of time as before, the trace in Figure 27 was obtained. If it is compared with Figure 25, the sound recording, then it is clear the impulse is not transmitted as a vibration through the spindle assembly. The long period of the impulse makes it very unlikely that the vibrations reverberate and smooth over the impulses. Therefore, the conclusion is that the noise is almost entirely radiated by the flat belt.

The acceleration measurements were repeated with the transducer mounted horizontally. This ensured the vibrations were not in one plane only.

The vibration of the belt cannot be readily measured. However, by changing the tension in the belt while it is moving it is possible to detect by ear a shift in frequency of the sound from the machine. Increasing the tension raises the pitch, and decreasing it lowers the pitch. The conclusion from this subjective test, together with the vibration measurements, is that the belt is a primary radiator of noise.



(a) Accelerometer Vertically Mounted

(b) Accelerometer Horizontally Mounted

Figure 27

Vibration Levels in the Spindle Support Arm

8.7 Narrow Band Frequency Analysis

The mechanism by which a source generates noise produces a characteristic noise frequency spectrum. Study of the spectrum can therefore be used to ascertain the part or parts of the machine responsible for the noise. In order to obtain sufficiently detailed spectra the analysing bandwidth must be very narrow. In this experiment signals were amplified from a microphone and a vibration transducer and recorded onto a Racal Store Four F.M. Magnetic Tape Recorder. The signals were then replayed and analysed by a Spectral Dynamics Real Time Analyser. This instrument has a constant bandwidth, instead of the constant percentage bandwidth of most analogue analysers. Over the range 0-5kHz the bandwidth is 10Hz, and over the range 0-2kHz the bandwidth is 4Hz.

The frequency distribution of sound at a point close to the belt, and therefore principally the sound radiated by the belt, is shown in Figure 28. The harmonics of the fundamental at 136Hz, corresponding to the rotational speed of 8,200 r.p.m., are clearly visible, particularly at the higher frequencies.

The vibration acceleration in the spindle support arm, and on the base of the bearing were recorded using a Bruel and Kjaer Accelerometer (type 8301) and a Precision Sound Level Meter (type 2203) fitted with an Integrator (type ZR0020.) The analysed frequency spectra are shown in Figures 29 and 30 . The transducer was mounted to a stud in the case of the spindle support arm, and by a magnet to the spindle bearing casing.

Again peaks were observed at regular frequency intervals. The frequency of each peak in Figure 29 is shown in Table 18, and is compared with the theoretical harmonics of the rotational speed. It is found that, if the spindle rotation frequency is Wo, then each peak can be described as having a frequency W, where:-

$$w = n\,W_o$$

$$n = {}^{m}/_{2}\,, \qquad m = 1, 2, 3, 4 \ldots\ldots$$

The measured frequencies of the peaks are in good agreement with the expected harmonics of the fundamental. There are also peaks between the harmonics, and these are exactly integer plus one half multiplies of the fundamental.

The half-harmonics are not caused by the bearing cage rotation. The cage revolves with the axes of the rollers, and therefore slower than the spindle itself. If the cage were to revolve at exactly half the spindle speed, then peaks at the half-harmonic frequencies would be expected. In fact it can be shown that the cage always

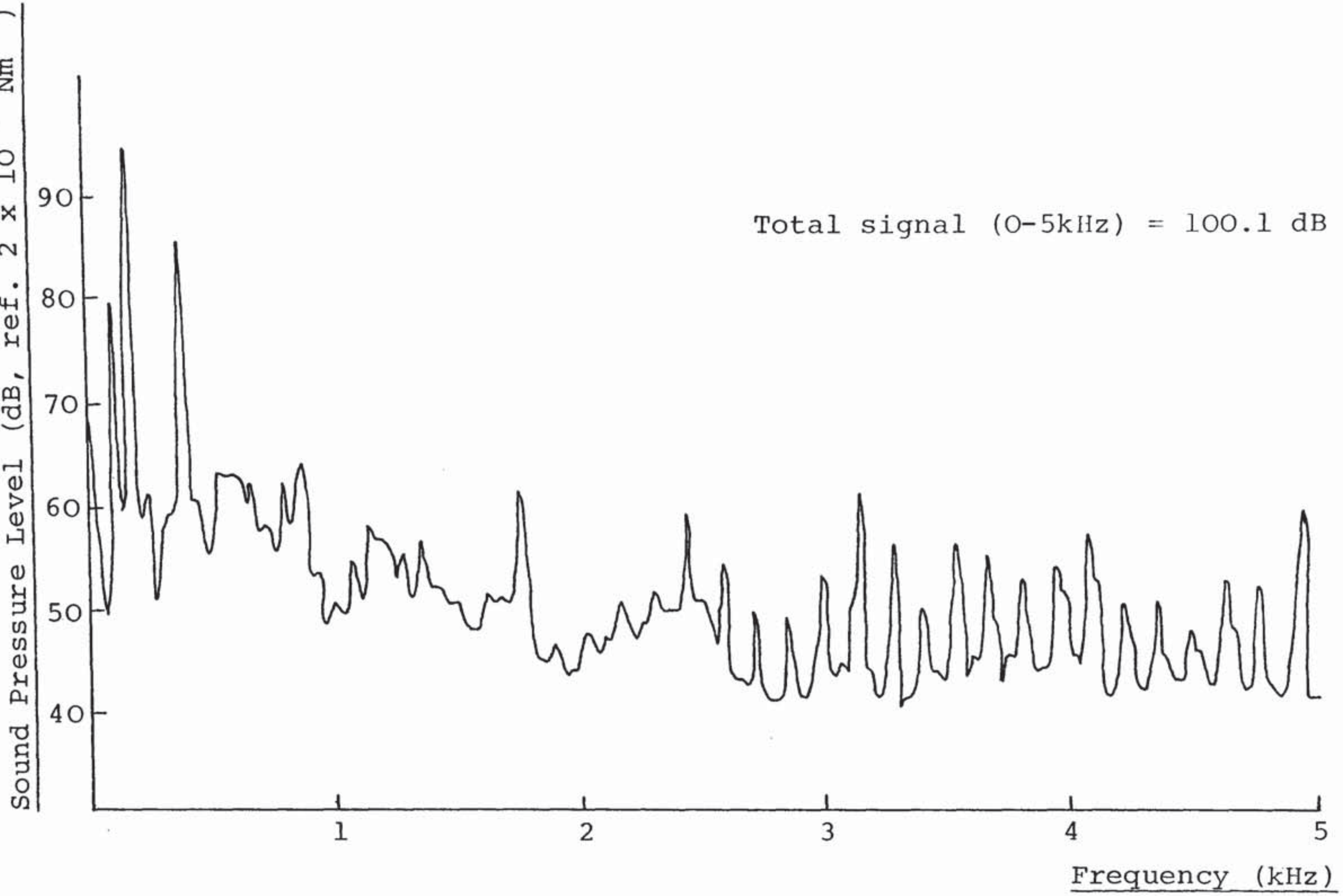


Figure 28

Sound Frequency Distribution close to the Uptwister Drive Belt

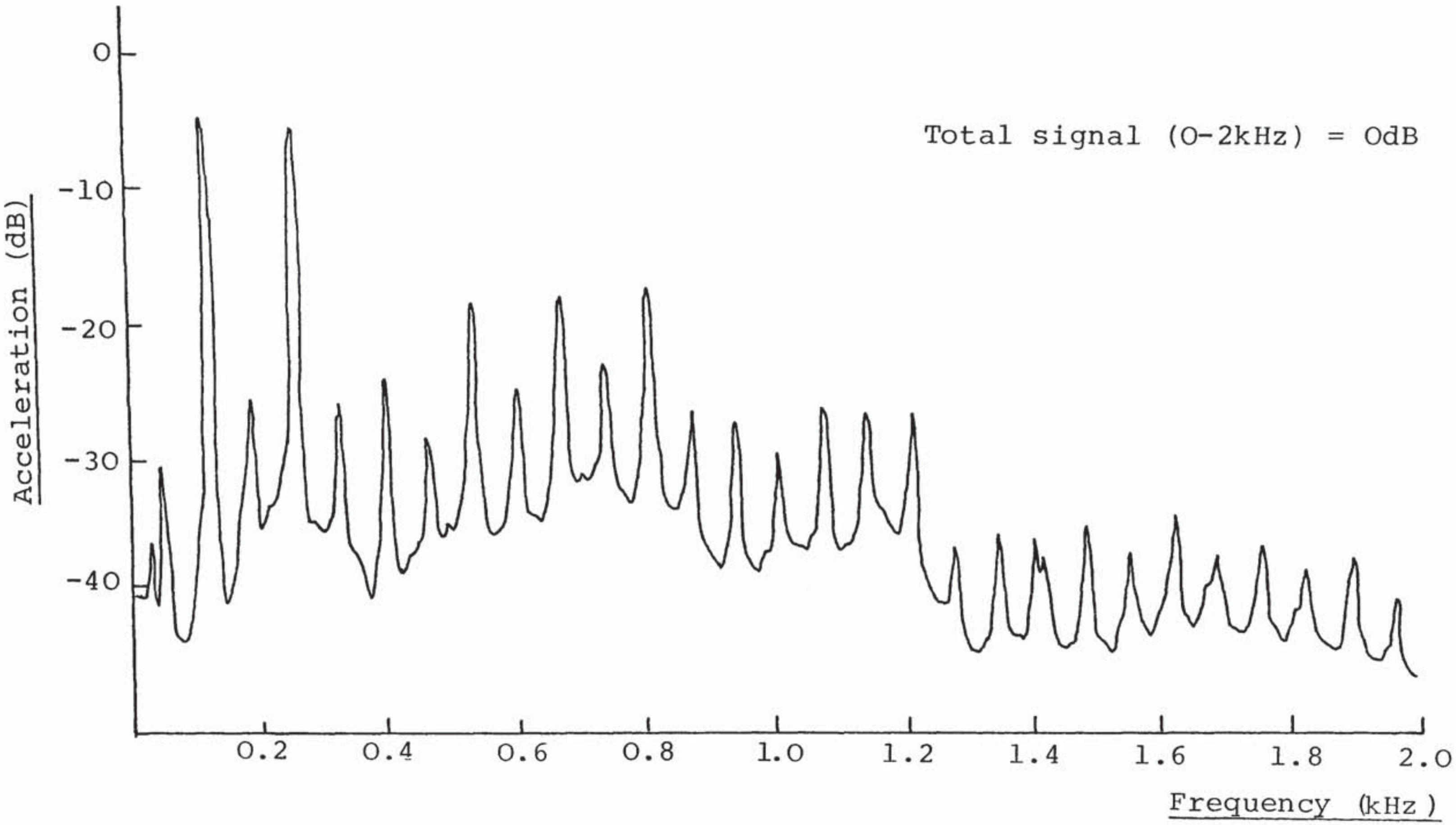


Figure 29

Vibration Acceleration of the Uptwister Spindle Support Arm

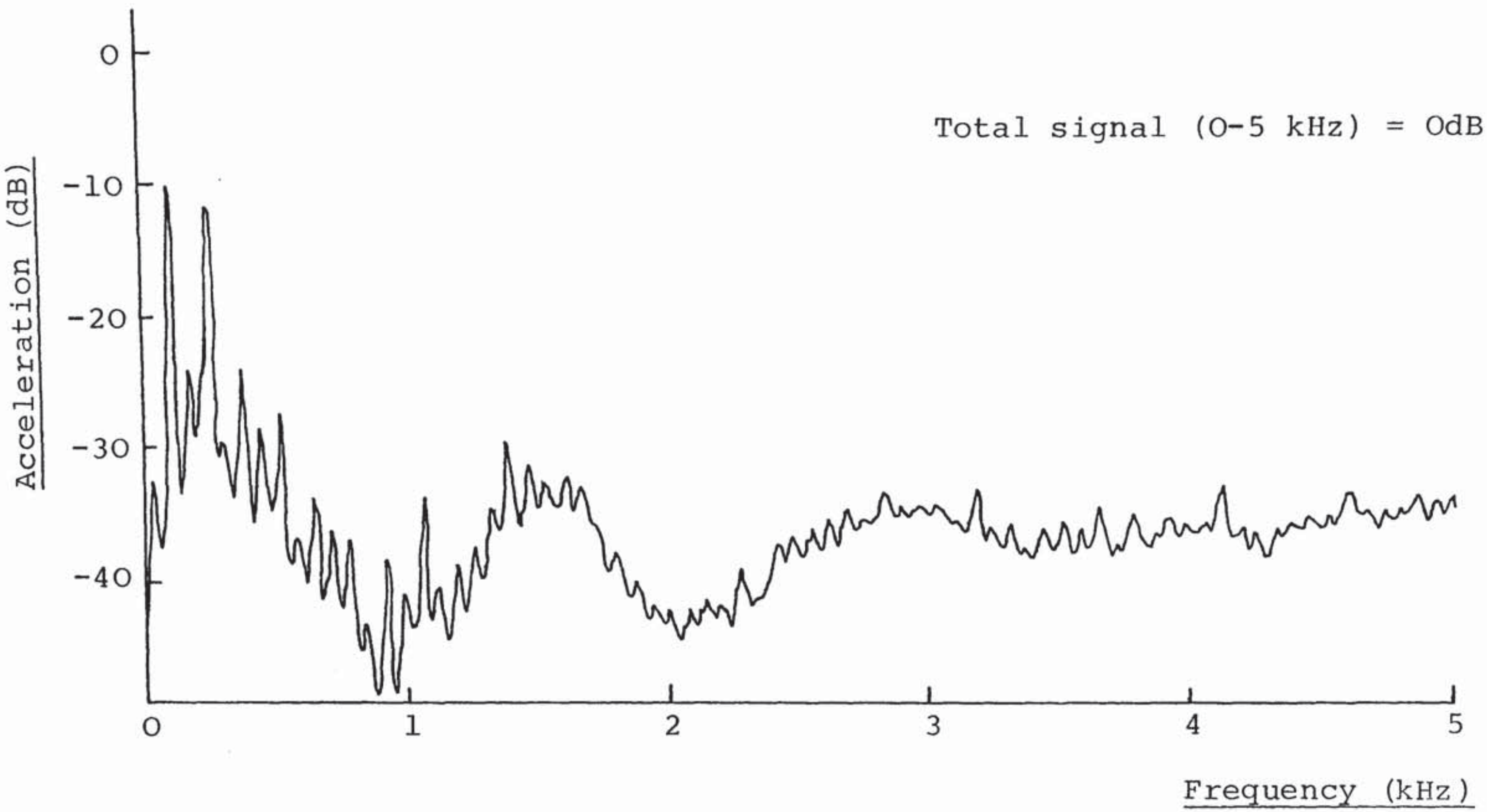


Figure 30

Vibration Acceleration of the Uptwister Spindle Bearing Housing

n	nWo	Frequency (Hz)
0.5	68	68
1	136	136
1.5	204	204
2	272	272
2.5	340	340
3	408	408
3.5	476	476
4	544	544
4.5	612	612
5	680	680
5.5	748	748
6	816	816
6.5	884	884
7	952	952
7.5	1020	1020
8	1088	1088
8.5	1156	1156
9	1224	1224
9.5	1292	1292
10	1360	1360
10.5	1428	1412
11	1496	1496
11.5	1564	1564
12	1632	1632
12.5	1700	1700
13	1768	1768
13.5	1836	1836
14	1904	1904
14.5	1972	1972

Table 18

Theoretical and Measured Peaks of the Sound Spectrum in the Operator Position (see Figure 29) rotates with a speed, ϕ , where:

$$\phi < \frac{\phi s}{2} \qquad \phi s = \text{spindle speed}$$

unless slip between the rollers and the stationary bearing housing is greater than that between the rollers and the spindle.

Assuming no slip between the roller and the surface, the ratio of the cage speed , ϕ, to the spindle speed, ϕ_s is given by:

$$\frac{\phi}{\phi s} = \frac{r}{r + R}$$

r = radius of inner race

R = radius of outer race

$$R > r, \text{ and hence } \frac{\phi}{\phi s} < 0.5 \text{ for all bearings}$$

It is unlikely that slippage would occur such that the ratio became exactly 0.5 with the accuracy of measurement obtained. The conclusion is that the half-harmonics are not generated by the bearing cage.

In fact the half-harmonics are natural oscillations of the system. The motion, in one dimension (x) of an undamped linear system is given by the differential equation:

$$\ddot{x} + p^2 x = F \cos wt$$

where $F \cos wt$ is the forcing function

P is the natural frequency of vibration

If suitable boundary conditions are chosen, Stoker[30] show the solution of this equation is:

$$x(t) = \left(A + \frac{F}{w^2 - p^2}\right) \cos pt - \frac{F}{w^2 - p^2} \cos wt$$

where $A = x$ at $t = 0$

The solutions $x(t)$ are only periodic in a limited number of cases, including those subject to the condition:

$$p = \frac{mw}{n} \quad \left(\text{provided } A + \frac{F}{w^2 - p^2} \neq 0\right)$$

w is the forcing frequency, which in the case of the spindles is 136Hz. p is the frequency of the resulting vibrations. The frequency peaks of the vibration spectrum (Table 18) would be expected as solutions of the equation:

$$p = \frac{mw}{n} \quad \text{for} \quad n = 2$$
$$m = 1, 2, 3, \ldots.$$

The half-harmonics occur when:

$$p = \frac{mw}{2} \quad m = 1, 3, 5 \ldots.$$

and these are called ultra sub-harmonics. Ultra sub-harmonics only occur in linear undamped systems, as discussed mathematically above, or in non-linear damped systems. The spindle assembly vibrates, therefore, under non-linear conditions.

8.8 Resonance in the Spindle Mounting Assembly

The rotating spindle is flexibly mounted with a rubber collet isolating the bearing housing from the supporting bracket (Figure 20). The purpose of the flexible mounting is to make the spindle rotate with the minimum out-of-balance force, and to prevent the transmission of vibrations to the structure of the machine. The use of such mounts was found by Crawford[31] to reduce noise levels significantly. The position of the spindle is maintained by the coil spring beneath the support.

The resonance of the spindle in its mounting was investigated using a vibrator coupled to the whorl of the stationary spindle. The response of the spindle support was measured using the accelerometer mounted as before. The spindle was excited by the vibrator with a constant force at single frequencies, and the unfiltered response was measured. The frequencies of the peak responses are shown in Table 19, and the acceleration measured at excitation frequencies close to the spindle rotation speed is shown in Figure 31.

The resonance of the system is very close to the rotation speed, the collet is therefore not acting an an isolator, but is actually amplifying the vibrations transmitted to the support. Varying the compression of the coil spring had little effect on the resonant frequency.

Frequency (Hz)	Acceleration Level (g)
54	3.9
80	4.5
130.5	12.8
391	3.0
579	.29
834	.31
1110	.14
1222	.08
2161	.11
2712	.07
3785	.20
5261	.58
5866	.24
8081	.15
11,760	.17

Table 19

Peak vibration levels measured on the Uptwister Spindle Support Arm when the Spindle Whorl was excited by a sinusoidal force scanning from 25 to 12,000 Hz

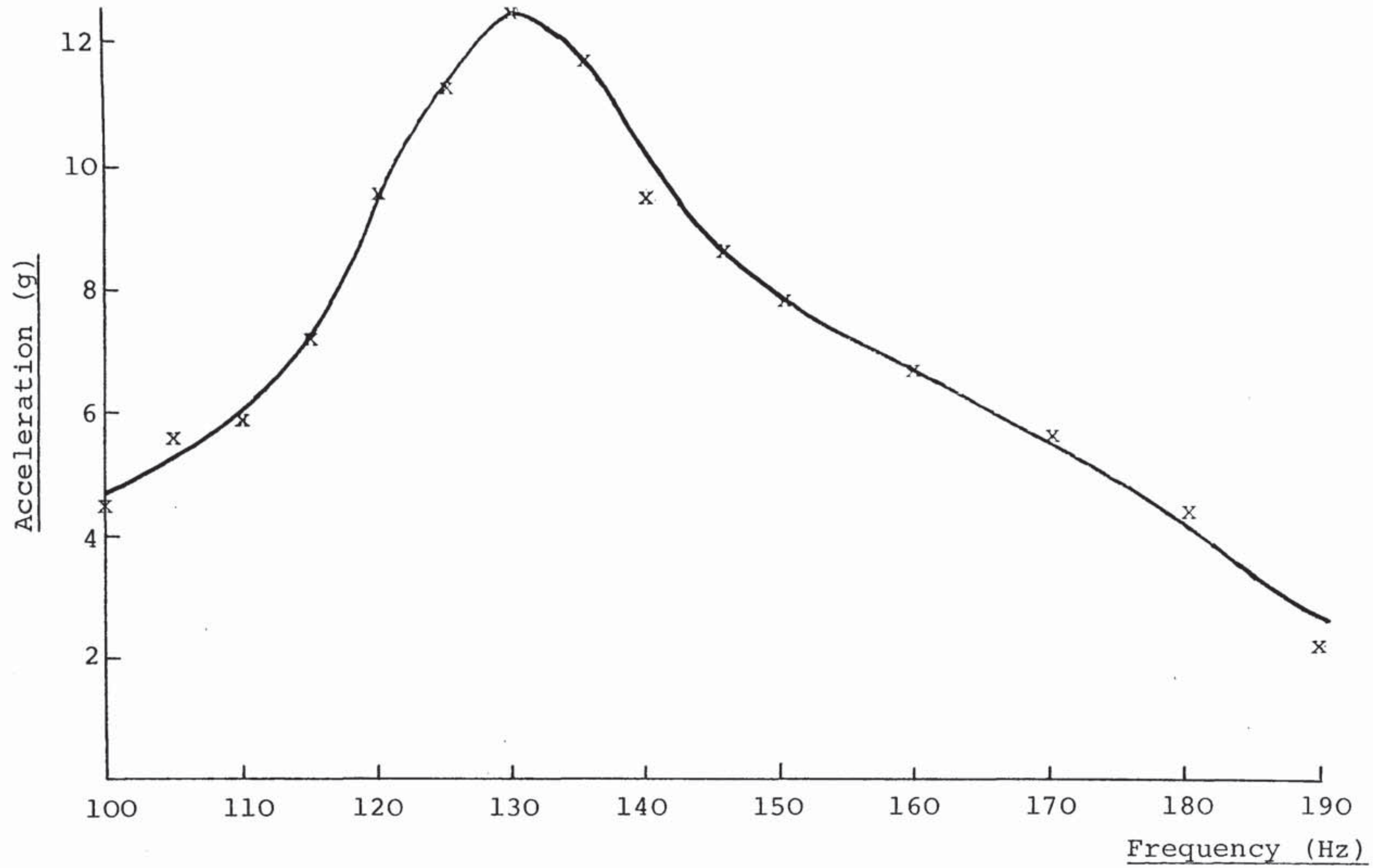


Figure 31

Vibration Level measured on the Uptwister Spindle Support Arm close to the 130.5Hz Resonance (see Table 19)

8.9 Reducing the Noise from Uptwisters

The important noise sources in an Uptwister are:-

1. The flap of the belt against the spindles (Belt/spindle interaction)

2. The spindle bearings

3. Bobbin windage

4. Yarn windage

The relative significance of the first three sources has already been discussed. Measurements on production machines showed that noise from a machine under load is less than 1dB greater than one without yarn.

It has already been noted that a decrease of 2dB can be obtained by using endless belts. Different types of belt material were tested, and an improvement of 1.5dB was obtained by using a chrome leather belt in place of the original nylon belt.

There would be a significant improvement in the noise emission from the structure of the uptwister if the method of support were to be redesigned. If the resonant frequency of the flexible rubber mounting were reduced to less than 50Hz the spindle bolster would be effectively isolated.

However most noise emanates from the belt and spindles, and the overall noise level would be only marginally improved by the measure discussed above. The alternative methods of reduction involve the use of screens and enclosures. The uptwister is symmetrical about a plane along the length of the machine. A sound absorbent screen along the centre line would screen the noise from the far bank of spindles. A reduction of up to 3dB might be expected. Measurement of the reduction was made by driving the spindles on one side only, and was found to be 2dB. A large amount of noise absorbent material in a shed full of uptwisters similarly treated would considerably improve the reverberation characteristics of the room. A reduction in excess of 2dB would be likely in practice.

A small absorbant lined box was constructed to cover the lower part of the spindle and the belt. The bobbin itself was not covered since continuous doffing (replacement of full by empty bobbins) is necessary with the machine running. The principal noise sources were enclosed within the box. For testing purposes the box was built to cover only two adjacent spindles. The remaining spindles were moved out of contact with the belt, and the noise from the two positions was measured with the enclosure in place, and with it removed. The comparative octave band levels are shown in Figure 32.

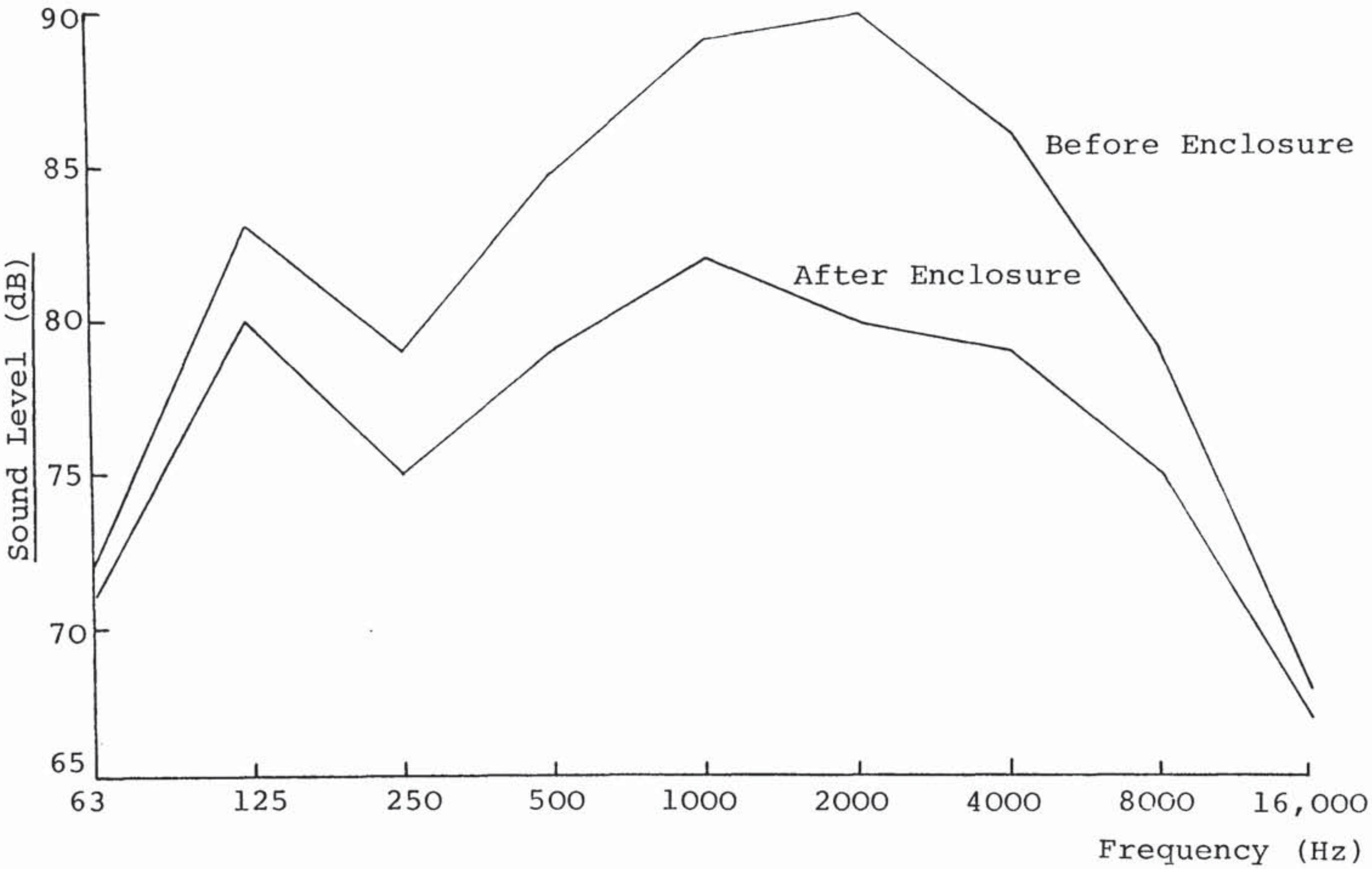


Figure 32

Octave Band Sound Levels of Two Uptwister Spindles showing the Effect of Enclosure of the Belt and Lower Spindle

The position of measurement was 0.5 metres from the spindles, and at a height of 1.0 metres. An accurate set of measurements could not be made at the standard distance of 1.0m due to extraneous noise from the belt in parts of the machine where the spindles were out of contact. The relative octave band levels indicate the reduction which could be obtained by an enclosure which included all positions along the machine. The 'A'-weighted reduction was from 95 dB(A) to 86 dB(A), that is 9 dB.

It would be incorrect to assume that all twisting and winding machines which are belt driven can be quietened by enclosure. High speed spindles would emit a higher level of noise from the rotating surface of the bobbin. Crawford[31] showed the intensity of sound generated by a rotating dipole is proportional to the sixth power of the rotation speed. An unconcentric bobbin surface will behave in a similar way. High speed processing machines may therefore not benefit significantly from enclosure of the driven part of the spindle and the belt. Enclosure of the complete bobbin could be effective, providing the doffing operation does not have to be made while the machine is in motion.

9

Noise Reduction - The Horizontal Strander

Chapter 9

Noise Reduction: The Horizontal Strander

9.1 Introduction

This chapter is devoted to a case history of a particular noise reduction project. The objective was to quieten the horizontal stranding machines used in the manufacture of steel tyre cord. The project was led by myself, with the backing of all the resources of the Engineering Development Department. The development of the project is traced from the Department's first involvement, to the implementation of the modifications to the first batch of machines on site.

9.2 The Horizontal Stranding Machine

Steel Cords Limited is a subsidiary company of Courtaulds engaged in manufacturing brass coated steel tyre cord used in strengthening vehicle tyres. The company employs approximately five hundred people. Part of the process of manufacture involves stranding several filaments into a single cord by twisting. There are two stages to the twisting process. Firstly, the single filaments are twisted using a stranding machine. The output from these machines are themselves twisted to form the final cord using a closing machine. There are two varieties of stranding machine, vertical and horizontal, differing in the weight of cord they are able to process.

There are 94 horizontal stranders housed in two sheds. Figure 33 is a diagrammatic illustration of the horizontal strander.

The operation is as follows. The bobbins holding the single filaments are supported on a creel at one end of the machine. One filament from each bobbin is unwound, and all are drawn together into the second stage of the machine, the torsion head. This is fundamentally a pulley which rotates at high speed about an axis along its diameter. The filaments of steel are wrapped several times around the pulley. False twist is introduced into the cord by this process. It is known as false twist, since twist builds up on either side of the torsion head in an opposite sense. Twists are able to pass around the pulley, and therefore as the cord is drawn through the torsion head the twists cancel. No net twist is introduced.

The purpose of the torsion head is to pre-stress the cord prior to the final collection stage, where real twist is inserted into the cord. The cord path is shown in Figure 34. This configuration introduces two turns for every rotation of the collection unit bowls. The torsion head rotation speed is high. The cord is overstressed to an extent, such that when the real twist is introduced there is no tendency to unwind. The "life" of the steel

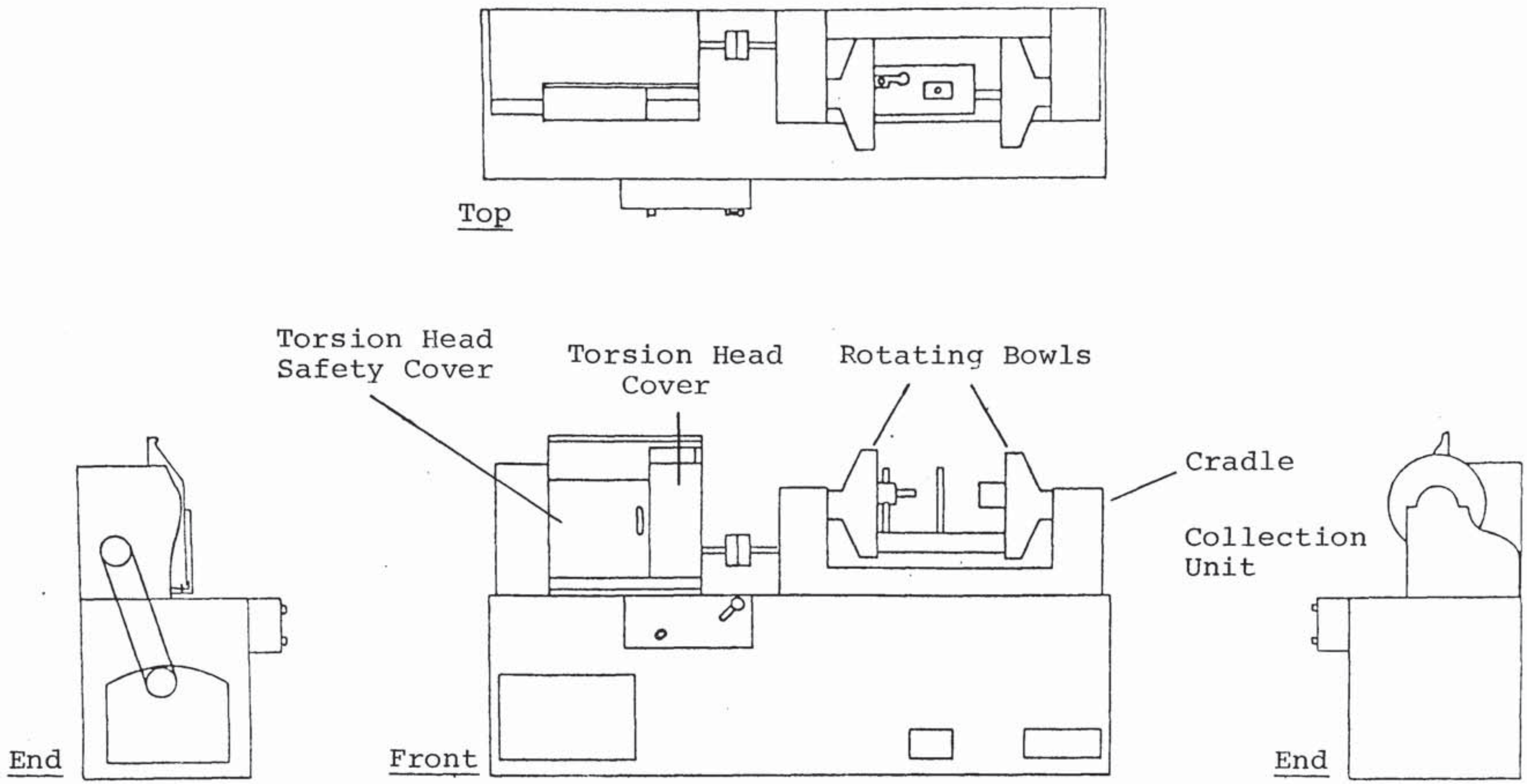


Figure 33

The Horizontal Strander (without the Creel)

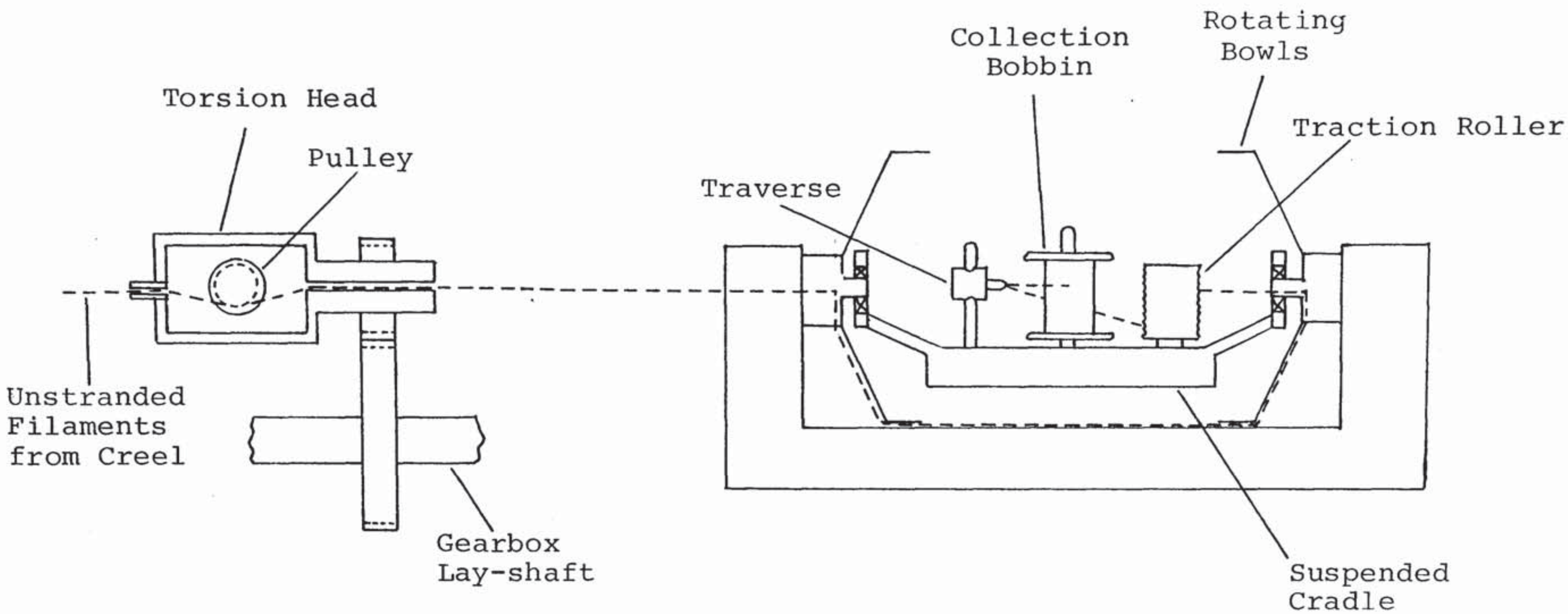


Figure 34

Diagram showing the Path of the Cord through a Horizontal Strander cord, the tendency to twist further or unwind when under no torsional stress, is determined by the relative speeds of the torsion head and collection unit.

A single 10 H.P. motor drives the torsion head and collection unit. The torsion head is housed in a box which also contains gears which bring the speed of the torsion head up to about 10,000 r.p.m. The minor adjustments in torsion head speed, required to produce a cord with zero life, are made by replacing one or two of the gears. The drive shaft also rotates the collection unit bowls, rotates the take-up bobbin and operates the traverse mechanism.

Two previous attempts had been made to quieten horizontal stranders. The first was a prototype free-standing hood made of wood and lined with a sound absorbant material. The hood was not airtight. It was to be attached to a hoist to provide access to the machine. It was abandoned because there was insufficient reduction in noise, and the use of a hoist would have been too cumbersome and expensive.

The second attempt was a redesigned torsion head gearbox, from which it was assumed most of the noise emanated. A prototype was built which used timing belts in place of meshing gears. Once again it was abandoned after a brief trial. The improved drive consistently failed mechanically, due to the inadequate rating of the belts and pulleys employed.

The pressure for reducing noise levels at Steel Cords has recently grown. As the awareness of the dangers of high noise levels has developed, a programme of hearing conservation has been introduced. The factory management have been very successful in persuading machine operators to wear hearing protection. However, whereas there were very few complaints by the operators about the high noise levels, there are now many complaints about the enforced wearing of ear muffs.

In addition there is increasing pressure on management from Factory Inspectors. Although no official action has been taken the Inspectors have indicated that they expect some progress towards lower noise levels. The chief competitors of Steel Cords have already reduced noise levels to below 90 dB(A) in their factory, which uses a different type of machine. Pressure therefore increases, since Steel Cords would have an unfair commercial advantage if they did not match the investment in noise control modifications.

Noise levels in the area around the horizontal stranding machines were found to be in the range 103 to 105 dB(A). Measurements were made at the typical position of an operators head as he patrols the machines. If a strander requires close attention, for example when a bobbin is full, the creel is empty or there is a break in the cord, the machine is switched off. The maximum level to which the operator is exposed is therefore 105 dB(A). The machines operate continuously, and therefore it was necessary to remove a single strander for detailed noise measurements. Noise levels in the vicinity of the closing machines indicate they alone would produce in excess of 90 dB(A) without the noise from the stranders in some sheds. The first part of the noise reduction programme was to quieten the horizontal stranders, but subsequent attention to the closers would be required if the target level of 90 dB(A) throughout the plant were to be achieved.

9.3 Proposals for Quietening the Strander

A typical horizontal stranding machine was removed from production and installed in the Engineering Development Department. This was to enable modifications to be made more easily using the resources of the Department's workshop, and to allow accurate assessment of the effectiveness of each modification in relatively quiet surroundings. The laboratory background noise was measured as 56 dB(A). Although this figure varied throughout the period of study, it can be shown that the background contribution is negligible if it never exceeds 10 dB less than the measured level of noise source and background combined.

Background level	l_b
Noise source under test	l_s
Measured noise level	l_m

If l_b, l_s and l_m are all sound intensity levels in dB(A) measured at the same position, it follows from the principle of superposition of energy:

$$10^{l_m/10} = 10^{l_s/10} + 10^{l_b/10}$$

If $l_b = l_s - 10$, then:

$$l_m = l_s + 10 \log_{10} 1.1$$
$$= l_s + 0.41$$

Therefore, if $l_b \leqslant l_s - 10$, the perturbation due to the background will be $\leqslant$ 0.41 dB.

The acoustic properties of the test room differ from those of the plant. The measured noise level of the strander at a distance of 1 metre was found to be 1.2 dB lower in the test room than in the plant (measured during the summer shut-down period.) The high reverberation time of the plant would account for the difference.

When the strander was first installed in the test area the noise levels were measured as a control for the comparison of subsequent modifications. The microphone was positioned at a distance one metre from the main frame of the machine, and moved parallel to the length of the machine with readings recorded at intervals of 200mm. The set of measurements were performed at heights of 1.0 metres and 1.5 metres. They are shown in Figure 35.

Noise levels were also measured at evenly spaced positions in the plane a distance 200 mm from the strander. The recorded levels were used to construct the contour diagrams (Figures 37-40) in the way described in Section 8.4.

The locus of each contour has to be estimated from the adjacent readings, but an accuracy of about one-fifth of the spacing between measurement points is possible; that is $\pm$ 30 mm. Note that the contours of adjacent sides are not continuous, since the microphone is turned through 90°.

The major noise source is clearly the torsion head box, containing the gears and torsion head. The torsion head is screened by a sliding, safety door in case it bursts while rotating. The door is not sealed and windage noise leaking around it explains the peak contour levels in that area. The torsion head itself is machined from a single block of steel and has a high moment of inertia compared with its mass. It is balanced after manufacture, but a small out-of-balance mass is sufficient to cause substantial vibrations. An improvement in noise level of 2 dB at position e in Figure 35 was achieved by balancing the torsion head accurately.

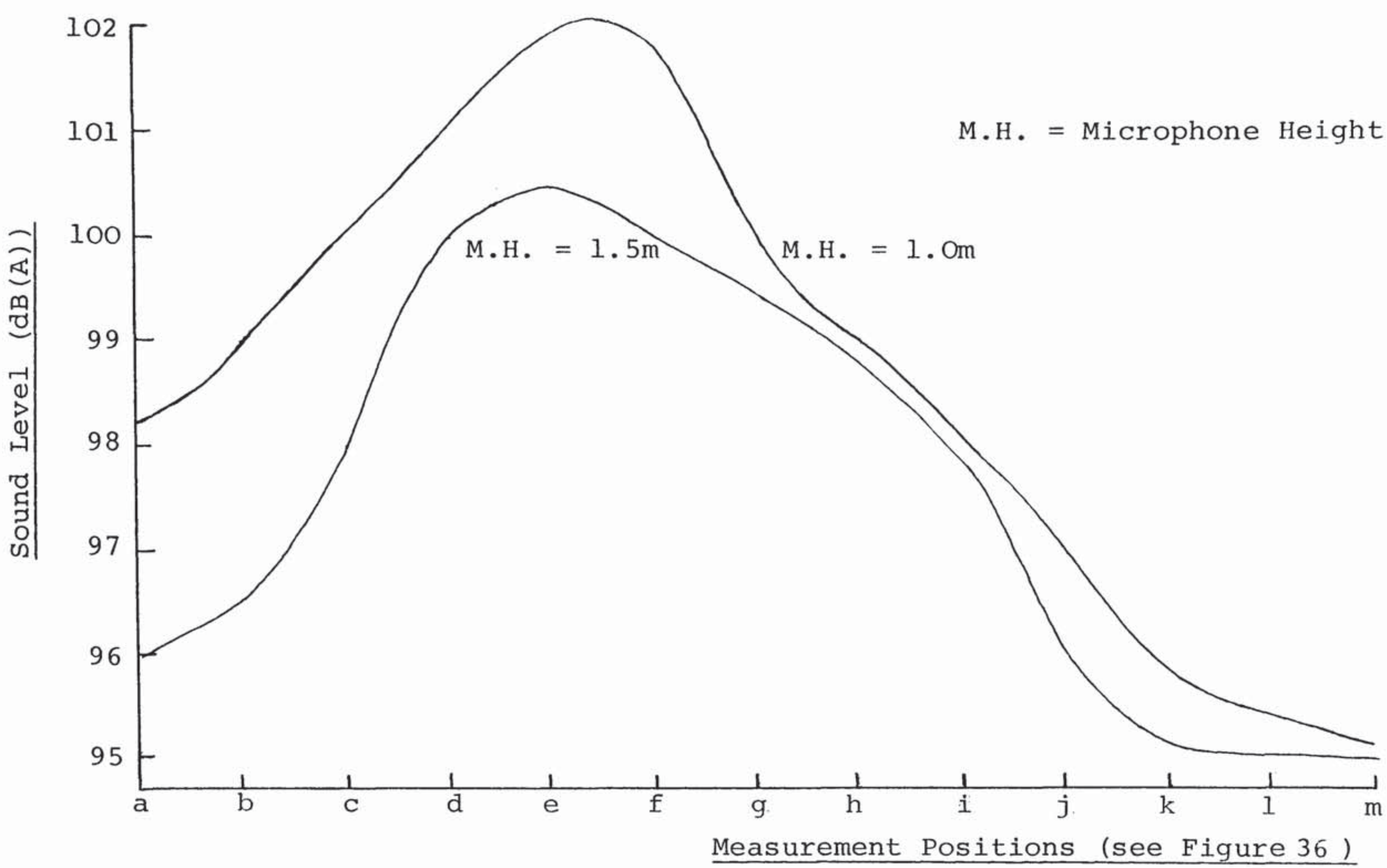


Figure 35

Sound Level at 1 metre from the Front of the Unenclosed Strander

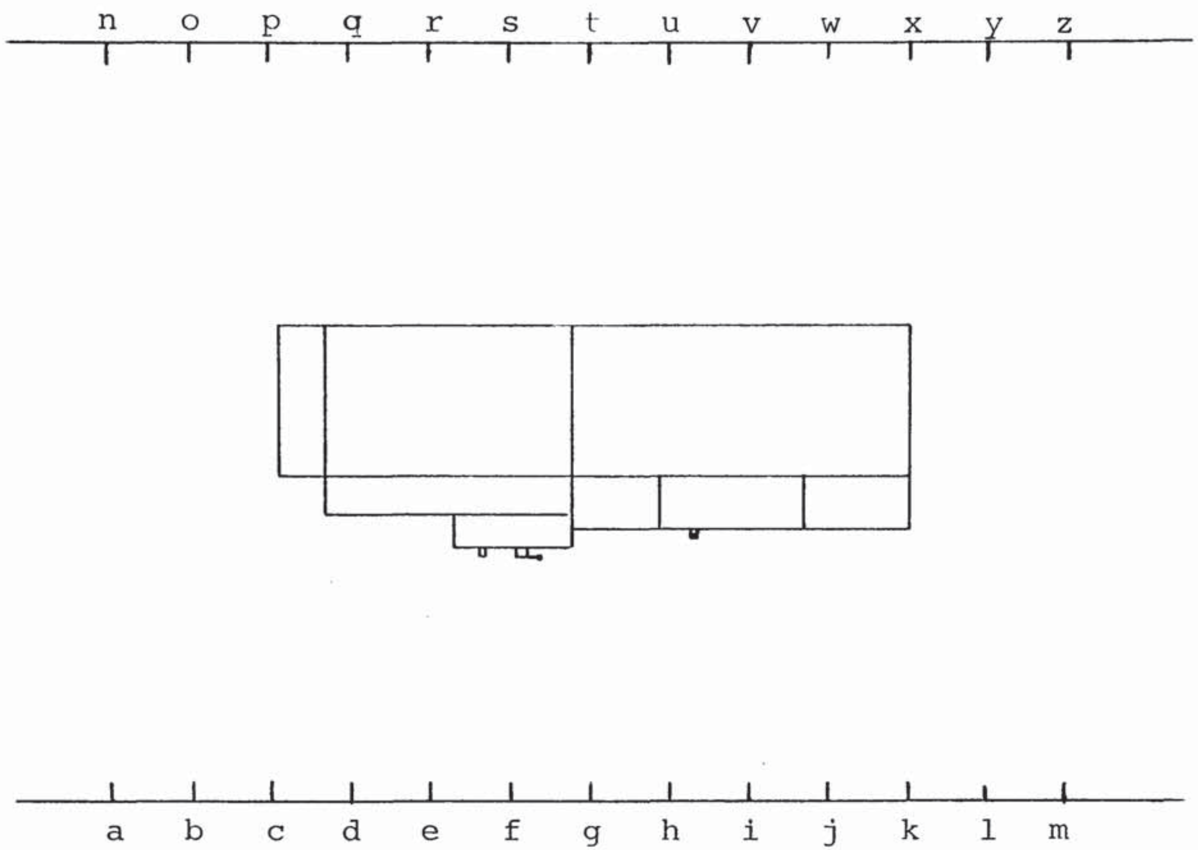


Figure 36

Measurement Positions at a Distance of 1 metre from the Strander

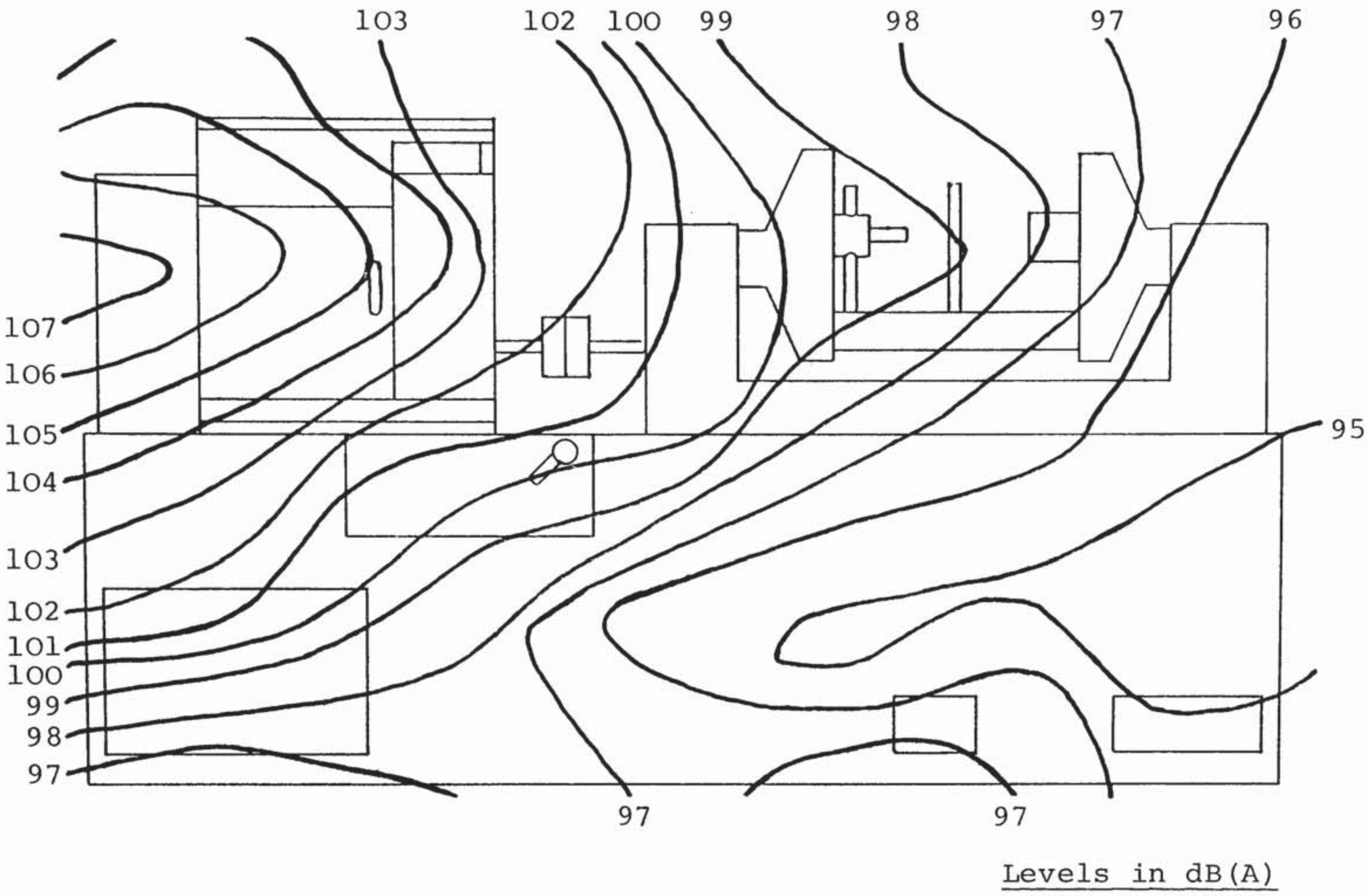


Figure 37

Noise Contours of the Strander - Front View

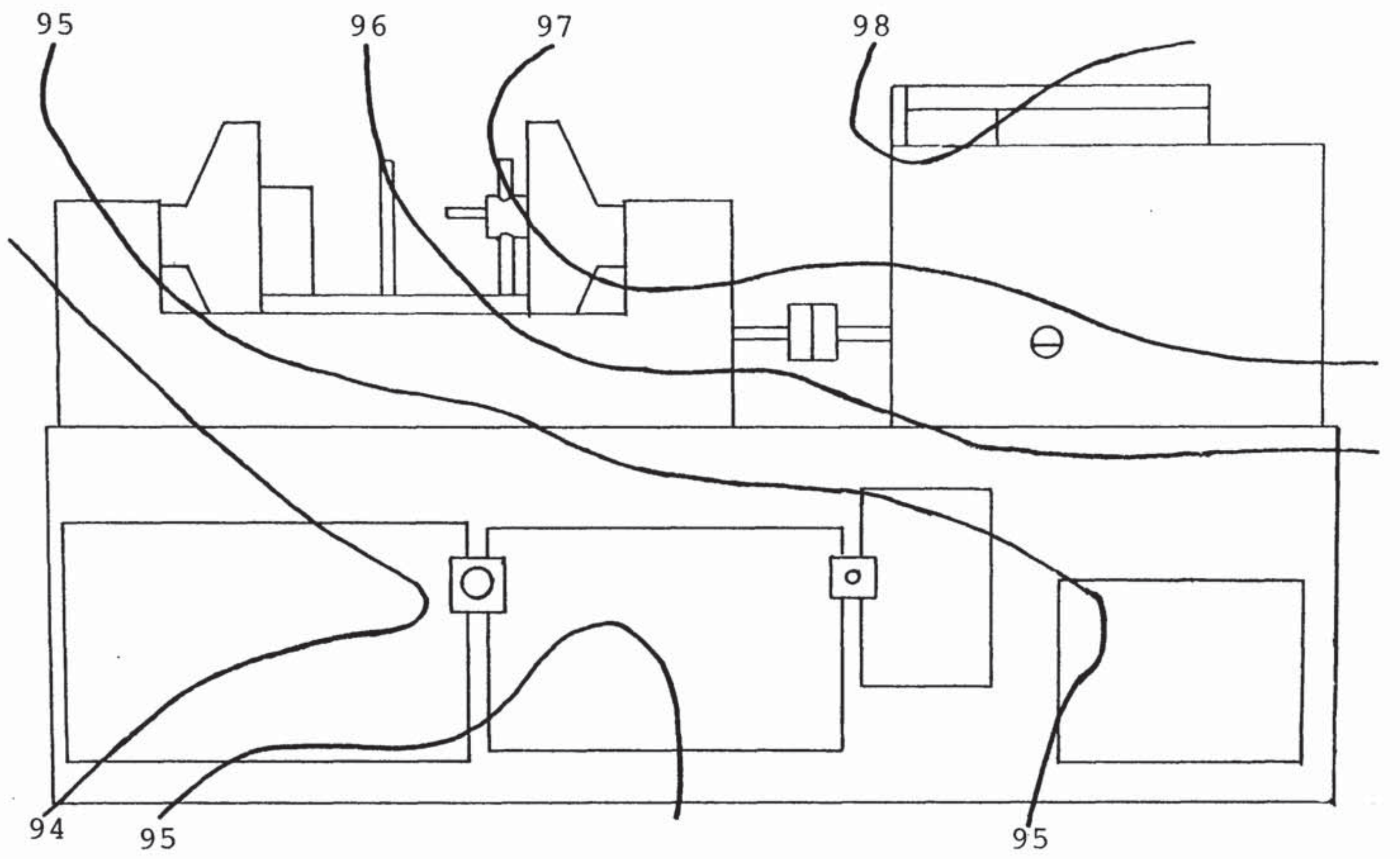


Figure 38

Noise Contours of the Strander - Rear View

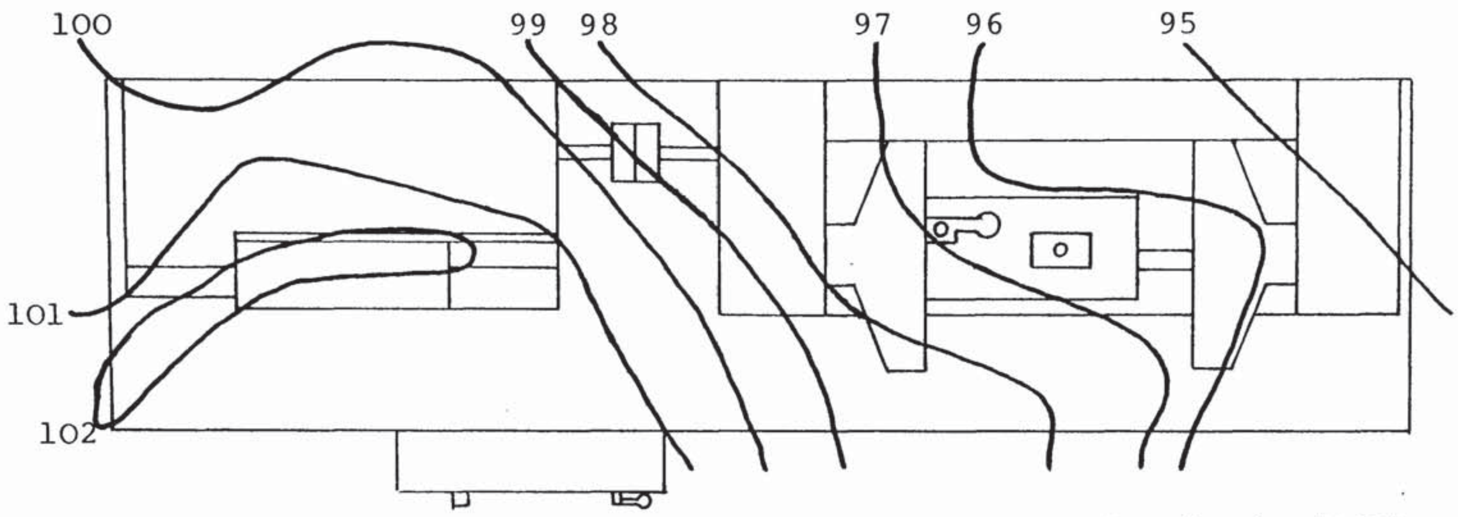
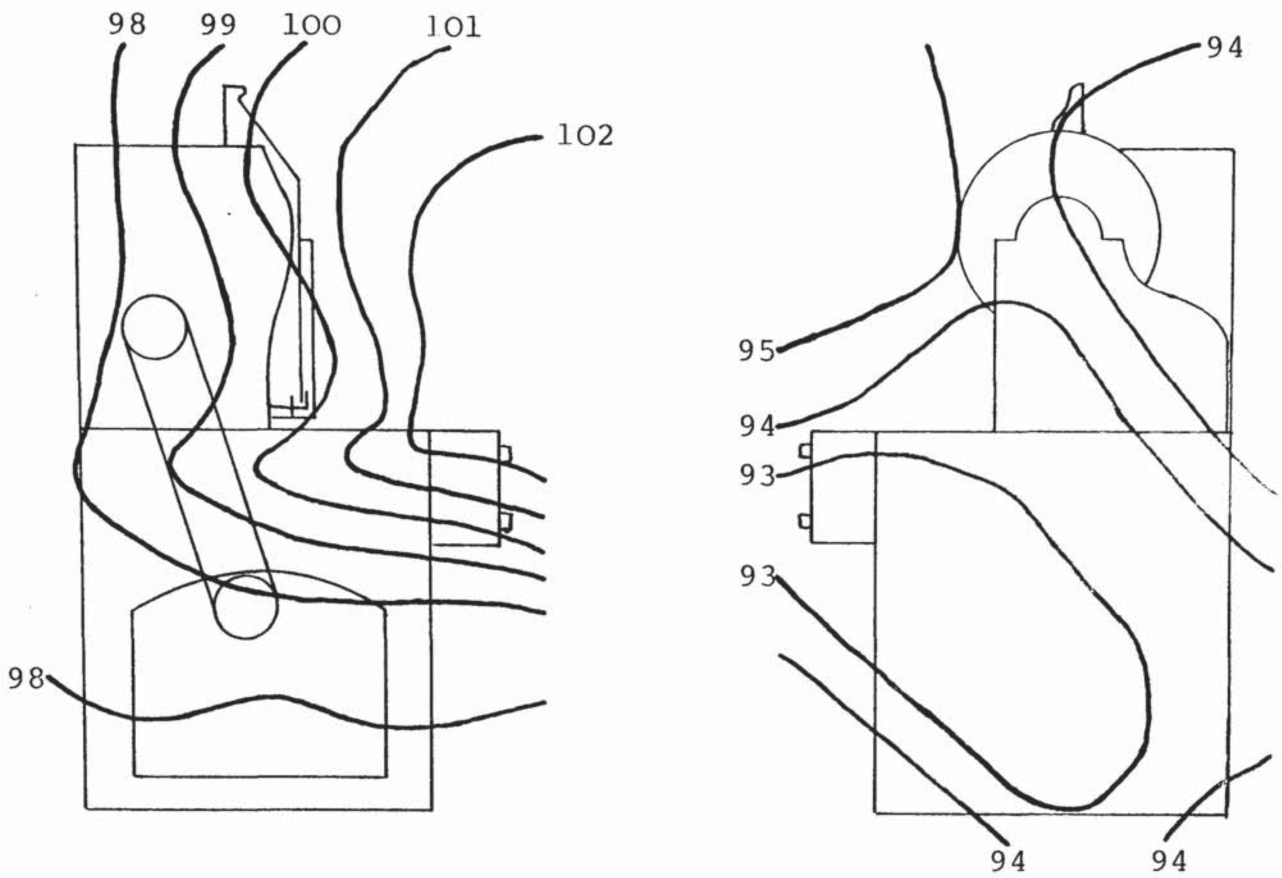


Figure 39

Noise Contours of the Strander - Top View



Levels in dB(A)

Figure 40

Noise Contours of the Strander - End Views

The gears also generate high vibration levels, which are transmitted to the box. If the torsion head box were to be quietened the gear train would have to be replaced, and the torsion head enclosed. Isolation of the shafts from the box would interrupt transmission of the vibrations. The present spur gears could be replaced by helical gears. It is doubtful if these measures alone would reduce the noise from the torsion head box to below 90 dB(A). The replacement of the gear train by timing belts would be a more certain method. A system of timing pulleys and belts was designed to achieve the required ratios. The sizes of the pulleys to transmit the power would be too large to be housed in the existing box. The box could be removed and the pulleys mounted directly onto the bed frame. A replacement box would then have to cover the new transmission and the torsion head for safety reasons. The noise level from the torsion head part of the strander could be reduced to 80 dB(A) by this method.

The replacement of the torsion head gearbox is an opportunity to replace the drive system of the strander altogether. If a synchronous motor were used, the rotation speed of the torsion head could be altered easily, without an interchange of gears. It would enable the company to meet the "life" specifications for steel cord more easily, and an improved product would offset some of the investment in converting the stranders.

The contribution of the collection unit to the overall noise level is measured by dismantling the torsion head gearbox. The levels are recorded in Figure 41 which should be compared with Figure 35 before the gearbox was disconnected. The measurements indicate that controlling noise from the torsion head part of the strander alone would not be sufficient. The frequencies of the sound emitted indicated windage was the prime source of noise from the collection unit. The two large bowls are smooth, apart from a single ceramic guide on each set. The blocks in which the guides are set are bolted to the bowls and stand proud of the surface. Identical blocks are bolted on the opposite sides of the bowls to maintain dynamic balance. When the blocks were removed and replaced by dummy blocks shaped to the contours of the bowl, the noise level was reduced by 2.5 dB due to the reduction of air turbulence. Although this attenuation would be sufficient, the variation from machine to machine would mean some would still be excessive. The collection unit noise level also produces a slightly greater noise level, approximately 1 dB, when carrying a load. This is due to the turbulence produced by the wire stretched between the perimeter of the rotating bowls.

Noise from the motor, the only other noise source,

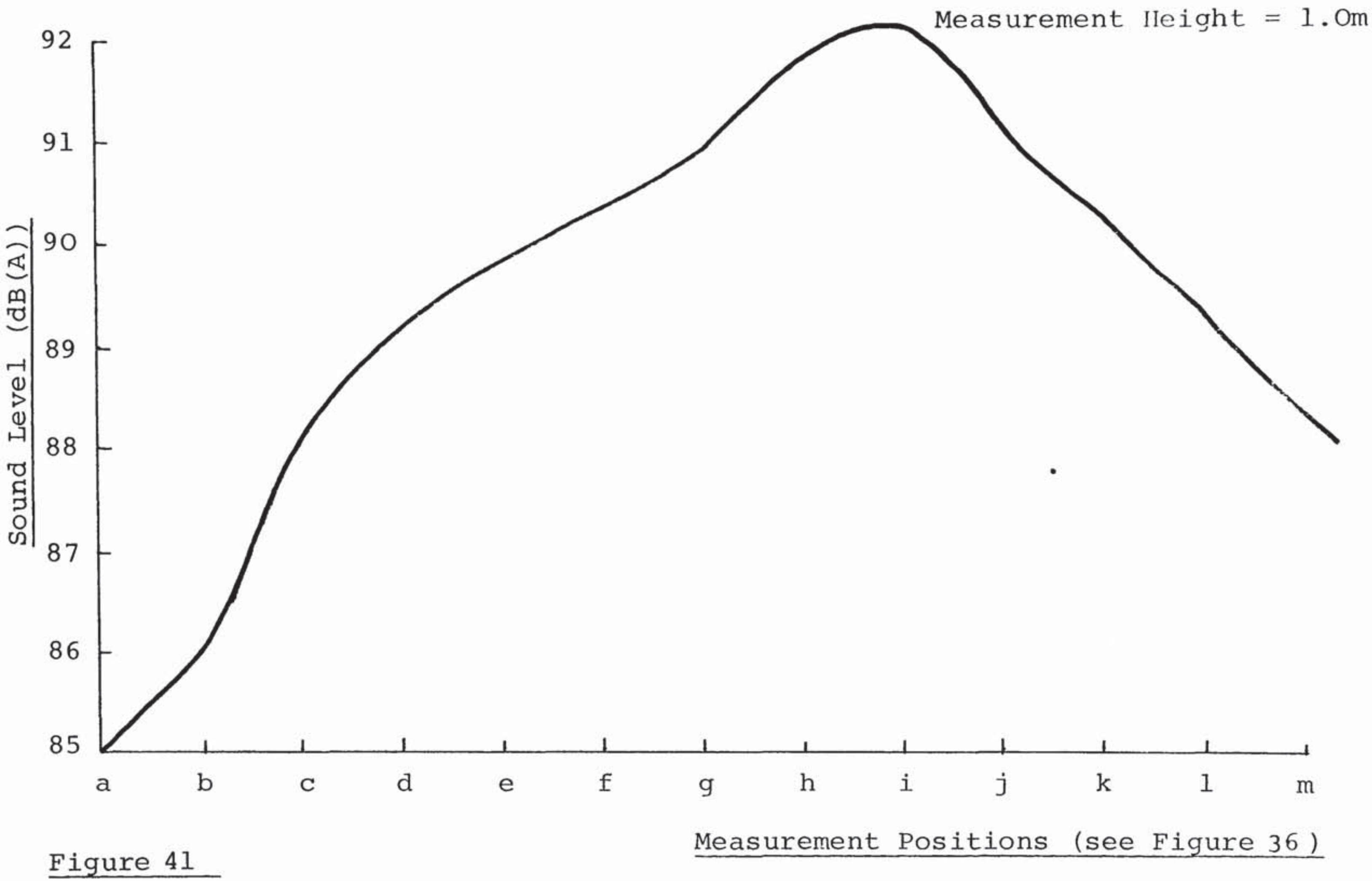


Figure 41

Sound Level at 1 metre from the Front of the Unenclosed Strander Collection Unit Only is not a significant contributor to the overall noise level. This conclusion is reached from measurements made with the motor under no load. It was impossible to measure the contribution of the motor while under load, since the torsion head noise is overwhelming. Undoubtedly, a large proportion of the overall noise is radiated from the bed frame of the strander. The vibrations from the torsion head transmitted to the frame could be interrupted by isolating the torsion head box and collection unit with a damped elastic material.

The modifications discussed above were put forward as proposals to the management of Steel Cords, as well as the option of machine enclosure. Without any experience of constructing enclosures it was difficult to estimate the cost. However, comparing the estimated cost of enclosure with the alternatives, the enclosure method was sure to be the cheapest method of achieving the target noise level of 90 dB(A) in the strander area. Although the advantages of replacing the drive by a synchronous motor with inverter were recognised, there was no prospect of obtaining sufficient funds to convert all the stranders in any realistic timescale. The management were reluctant to consider timing belts as a suitable alternative to gears after the unsuccessful earlier attempt. An enclosure also has the advantage of an almost unlimited degree of noise reduction, since the attenuation can be increased by changing the wall construction. Thus, Engineering Development Department were able to guarantee that the target noise level would be met, which would not have been possible with the alternative methods.

As a result of discussions with several representatives of the small firms who offer a noise reduction service on a contract basis, it is apparent that the certainty of being able to achieve attenuations specified in the contract is a major reason why enclosure is far more common than any other form of noise control.

9.4 Design of the Enclosure

The strander enclosure had to satisfy four requirements. Firstly it had to attenuate the noise to a satisfactory degree.

It could not interfere with the operation and maintenance of the strander, and therefore access had to be provided. The construction of the enclosure had to be able to withstand rough treatment without sustaining damage. Finally, the temperature of the strander could not be excessive inside the enclosure.

The target noise level for the shed was 90 dB(A) at all positions where operators normally stand. Each strander must not be responsible for more than 85 dB(A) if this target is to be reached, since the summation of noise from each strander is estimated to be not greater than an additional 5 dB. The direct field contribution to the noise level from each strander as measured at a point midway between two adjacent stranders is shown in Figure 42 . The levels are calculated using the inverse square law, and are relative to the contribution from the nearest machine, which is at a distance of approximately 1 metre. The enclosed strander is assumed to radiate sound uniformly in each direction. At distances greater than 1.0 metres the radiation is approximately spherically symmetric. The direct field from the more distant machines is modified by the screening of the interposing machines, but since the distant machines make a small contribution, the screening effects can be ignored. Reflected sound from all machines in the room reaches the measuring position, and the total predicted sound level is the sum of the direct field sound intensities and the reverberant sound intensity.

The figure of 5 dB to be added to the level of a single machine is obtained as follows:-

Single machine - operator position	85 dB(A)
Strander adjacent	85 dB(A)
Direct field from other stranders	83.4 dB(A)
Reverberant field	83 dB(A)
Total	90.2 dB(A)

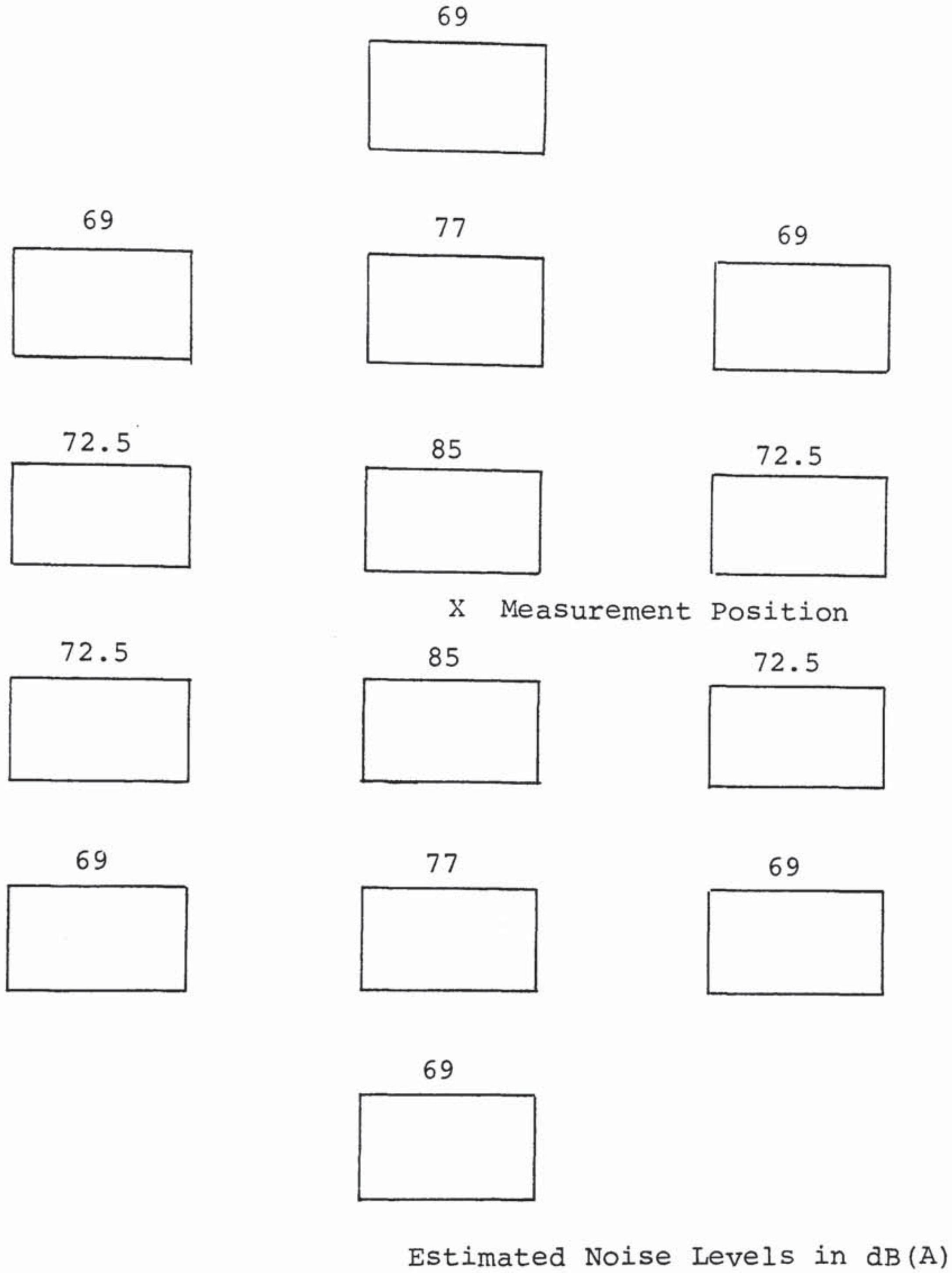


Figure 42

Direct Field Contribution from Adjacent Stranders

In order to ensure that the plant levels do not exceed 90 dB(A), an attenuation of 17dB was needed.

The required attentuation was achieved by covering the torsion head box and collection unit with a well sealed enclosure constructed of 18 SWG mild steel sheet. All joints were made as air-tight as possible using a 3mm neoprene seal. The steel sheet was lined with 25mm "Rockwool"[32] mineral wool. The "Rockwool" has to be protected from the large amount of oil in and around the stranders by "Melinex"[33], an oil resistant film. The "Melinex" and "Rockwool" were covered with perforated metal sheet which has a negligible effect on the acoustic properties of the enclosure, but protects them from the occasional failing steel strand when the cord breaks, and holds them in position. A section through one of the panels is shown in Figure 43. Vibration measurements showed that much of the noise from the base frame was as a result of transmission from the torsion box and collection unit. The enclosure had then either to cover the whole machine to the ground, or alternatively, the upper parts without the base, providing the vibration transmission could be interrupted. Experiment showed that the radiation from the base could be adequately reduced by raising the torsion box and collection unit on ½" "Tico"[34] pad, a rubber-cork material.

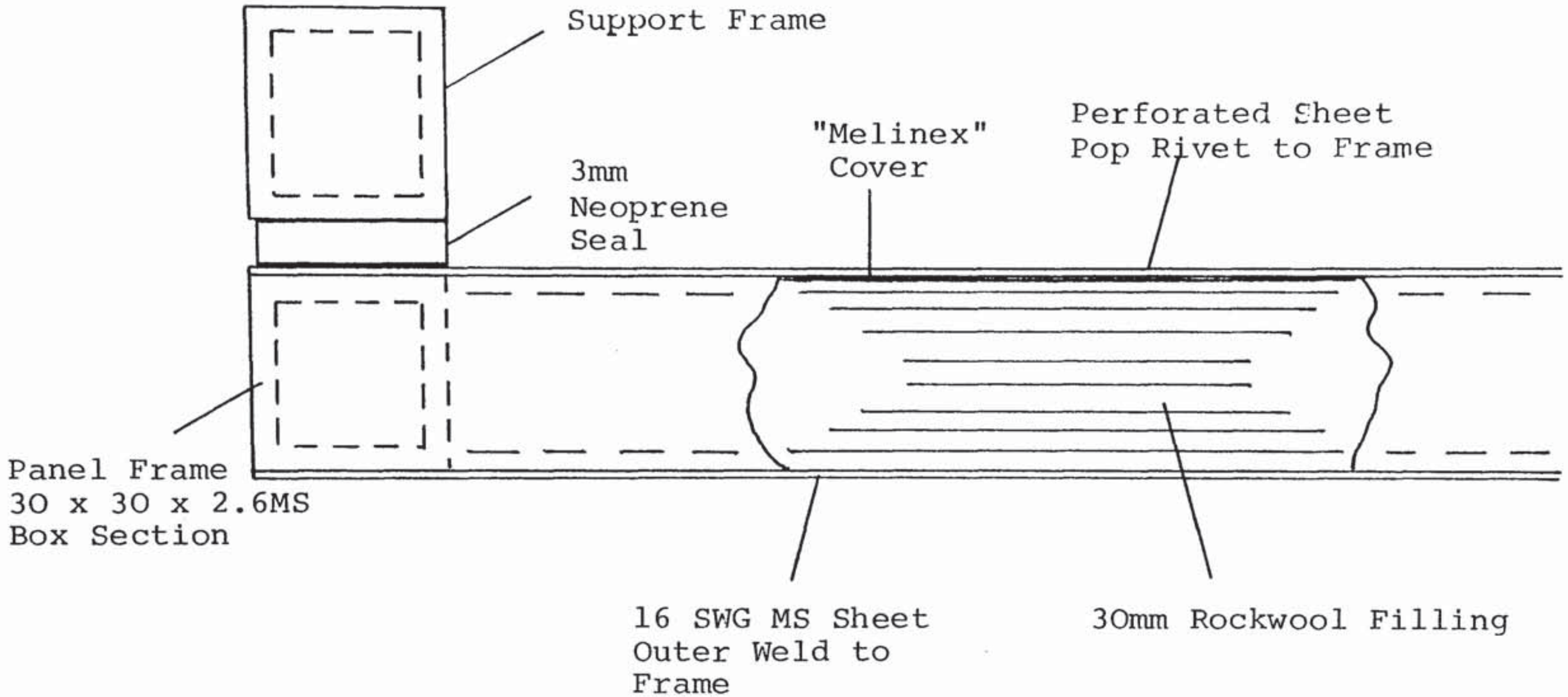


Figure 43

Section through Acoustic Enclosure Skin

There are two entirely separate functions of the enclosure skin. The steel sheet box acts as an acoustic insulator, preventing the passage of the sound energy by virtue of its mass and reflecting the noise from the strander back into the interior. If mild steel sheet were a perfect insulator, a complete box without any gaps would contain an ever increasing sound pressure level as more sound energy was generated. In practice all materials transmit a proportion of the incident sound energy depending on the frequency. The octave band sound reduction indices for 18 SWG mild steel sheet are given below, each figure representing the ratio of transmitted sound intensity to incident sound intensity at that particular frequency.

Octave Band	125	250	500	1000	2000	4000
Sound Reduction Index (dB)	12	19	25	29	31	34

Although part of the incident sound energy is transmitted, a large proportion is reflected and the reverberant sound pressure level inside the box is high. The second function of the enclosure skin is to absorb some of the sound energy and convert it to heat energy. This is the role of the mineral wool. The mineral wool does not reflect sound like the steel, but the passage of the transmitted sound causes the vibration of the fine fibres in the wool. Hysteresis in the bending moments and friction between adjacent fibres results in the attenuation of the transmitted sound. The sound absorption coefficient defines the proportion of incident energy absorbed by the material at a particular frequency. The sound waves in a reverberant chamber, such as the strander enclosure pass backwards and forwards through the absorbant material between reflections. The sound intensity, E, at any point in the enclosure is the sum of the separate intensities from each reflection.

$$E = e + (1-a)e + (1-a)^2 e + (1-a)^3 e + \dots.$$

Where e is the generated energy, and a is the absorption coefficient of the material. The series converges, such that for an infinite number of reflections:

$$E = \frac{e}{a}$$

The sound intensity inside the enclosure is therefore increased by $10 \log_{10} {}^1/a$ decibels. The sound absorption coefficients in each octave band are shown for 25mm mineral wool, density 144 kg/m^3, together with the predicted increase in intensity due to reverberation. This is the intensity of the sound incident on the steel sheet of the enclosure, and the transmitted intensity can therefore be calculated. As Table 20 shows, the 'A'-weighted intensity is reduced from 101 dB(A) to a predicted 79.5 dB(A) by the combined effect of steel sheet and absorbant, an

Octave Bands	125	250	500	1000	2000	4000
Machine octave band level at one metre (dB)	87	92	102	96	88	80
Absorption co-efficient (normal incidence value)	0.10	0.15	0.45	0.75	0.85	-
Increase due to reverberation (dB)	10	8.2	3.5	1.2	0.7	-
Machine level including reverberation (dB)	97	100.2	100.5	97.2	88.7	80
Attenuation by 18 SWG sheet steel enclosure (dB)	12	19	25	29	31	34
Resulting octave band levels measured in the same position as (1) above (dB)	85	81.2	80.5	68.5	57.7	46
'A'-weighting	-16	-9	-3	0	+ 1	+ 1

Unenclosed strander - 101 dB(A)

Enclosed strander - 79.5 dB(A)

Table 20

The Octave Band Attenuations of the Strander Enclosure attenuation of 21.5 dB.

The estimate involves several approximations. The complex shape of the machinery inside the enclosure increases the effective absorption coefficient, and the inevitable small gaps in the steel box reduce the effective insulation. However the calculation showed that the proposed enclosure skin was of the correct order of performance, and confirmation could be obtained by testing a prototype model.

The acoustic properties of the proposed enclosure were defined relatively easily. The chief design problem was to produce an enclosure which would cause minimum interference to the operation and maintenance of the strander. This required lengthy discussions with operators, engineers and foremen at Steel Cords, and observation of the operators at work. The detailed design work was undertaken by a Senior Designer from the Engineering Development Department.
The following points summarise the features of the enclosure which were included in the prototype model.

1. Lifting doors with pneumatic assistance to provide easy access to the torsion head safety cover, and to the bobbin resting inside the collection unit.

2. A detachable panel, held by quick-release fasteners, to facilitate access to the gear box in order to change torsion head rotation speed.

3. Bolt-on panels over the remainder of the enclosure which can be removed to allow access for maintenance. The panels are bolted to a frame consisting of three hoops of box section.

4. Magnetic and pneumatically operated bolts on all doors to prevent the machine starting with the doors open, or opening of the doors with the machine still in motion.

Designs for the enclosure were approved by the management at Steel Cords, and the prototype model was constructed. Considerable alterations were made in the details of the enclosure as a result of sound level measurements, and from observations regarding operation and maintenance by representatives of Steel Cords. In particular it was found necessary to place baffle plates over the holes in the sides of the base to attenuate the noise from the interior of the base structure

9.5 Testing the Enclosure

The acoustic performance of the final prototype enclosure was assessed by repeating those measurements made earlier, but this time with the enclosure in position. The sound levels at a distance of 1 metre from the strander are shown in Figures 44 and 45. The maximum level is 82 dB(A) at a height of 1.5 metres (corresponding to a standing operator) compared with a maximum of more than 100 dB(A) before the introduction of the noise control measures. The mean attenuation is approximately 18 dB. The close contouring measurements, made at a distance of 200mm, were repeated and are shown in Figures 46 to 49. Comparison with the equivalent Figures 37 to 40 show the noise emission to be more uniform, which indicates there are no isolated weaknesses in the enclosure, and that the noise control programme has been efficiently devised. The slightly higher levels emanating from the lower part of the structure are acceptable since it is furthest from the operators' ears.

The temperature inside the enclosure became a major cause for concern. Mineral wool is a good thermal insulator as well as being a good acoustic absorbent. The temperature of the torsion head bearing cover was measured at 62.5^{o}C after more than 90 minutes continuous operation, compared with 33^{o}C without the enclosure in place. Typical temperatures in the production stranders were found to be about 40^{o}C in the same part of the machine. Comparison of the temperatures of the bearing caps in the collection

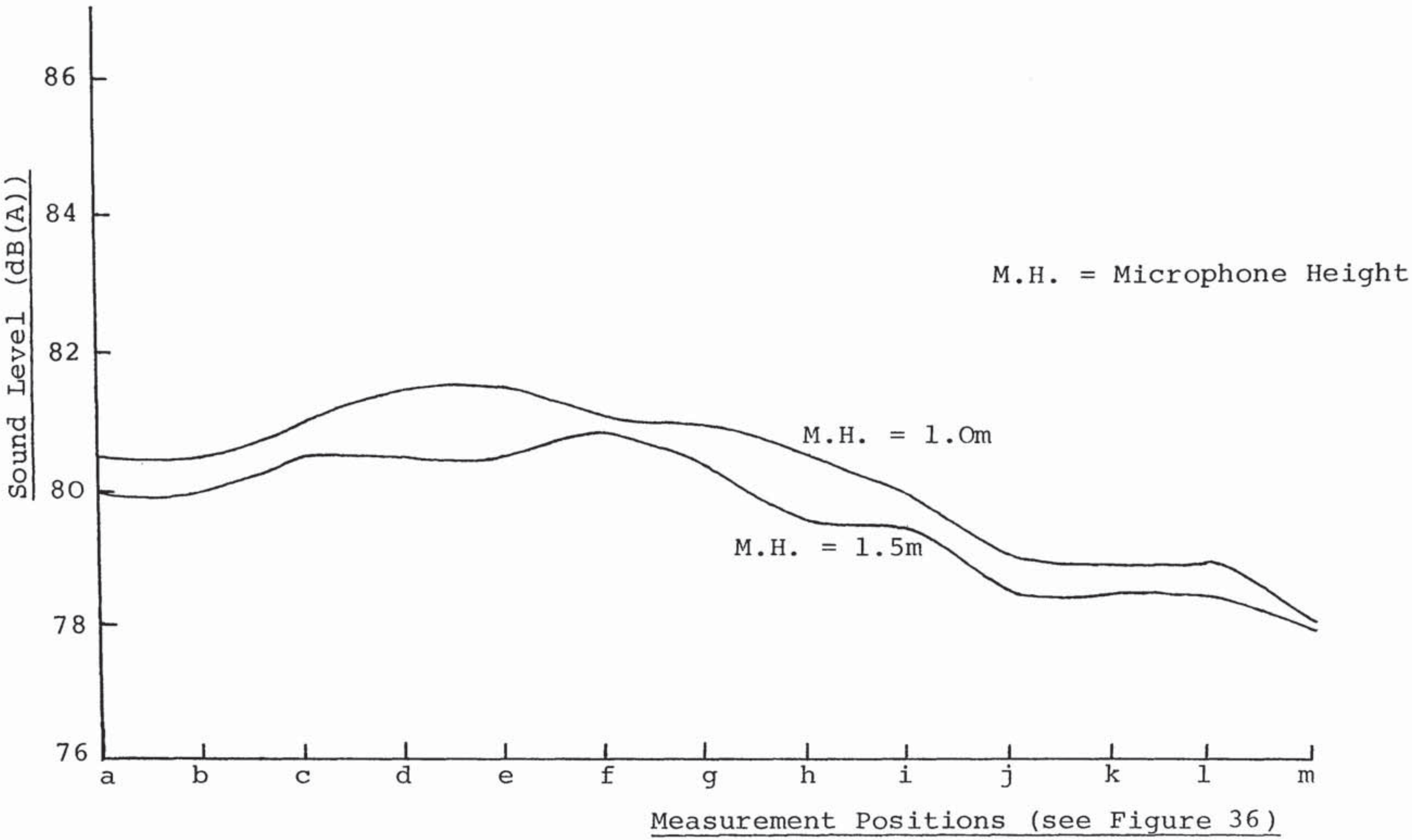


Figure 44

Sound Level at 1 metre from the Front of the Enclosed Strander

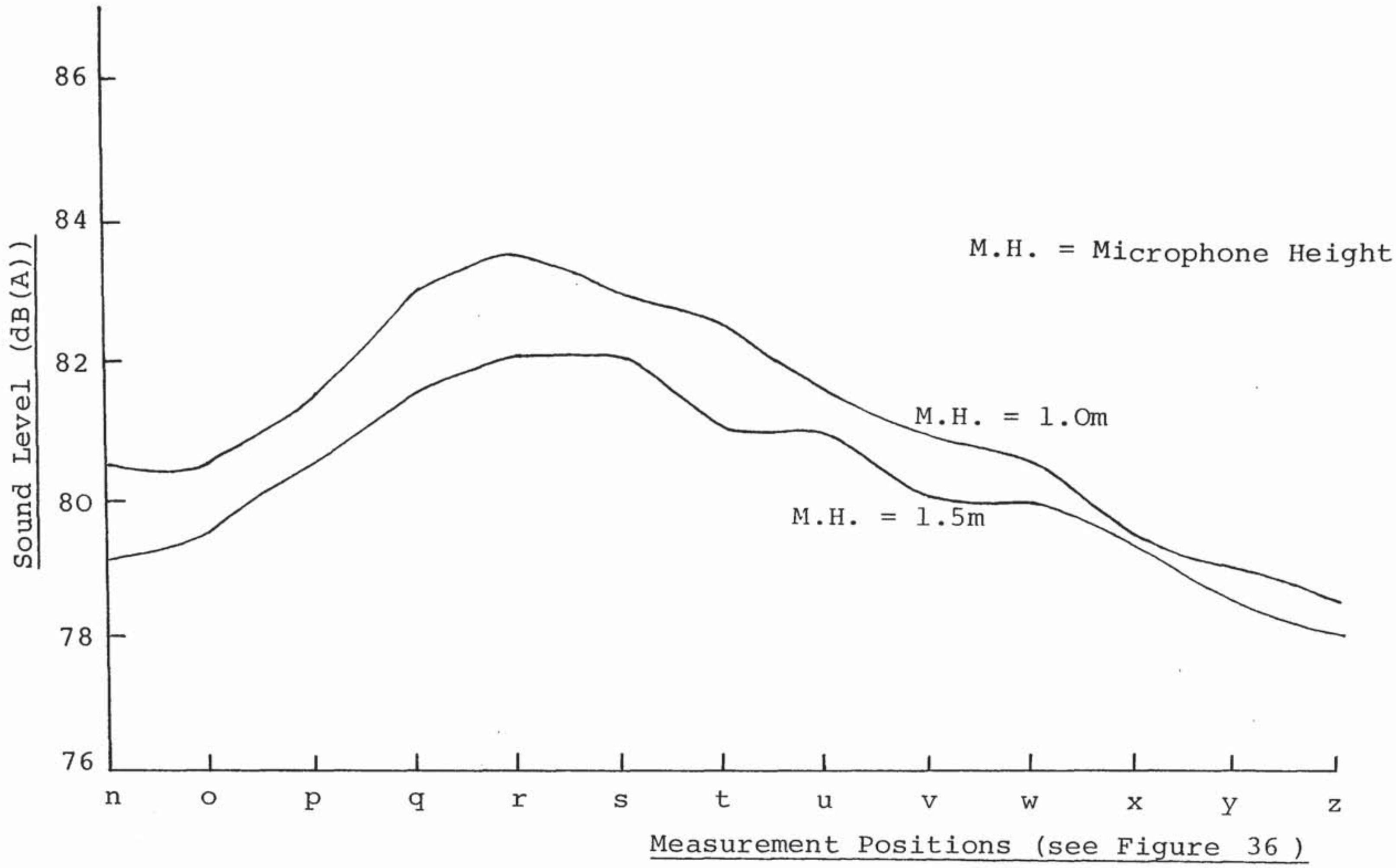
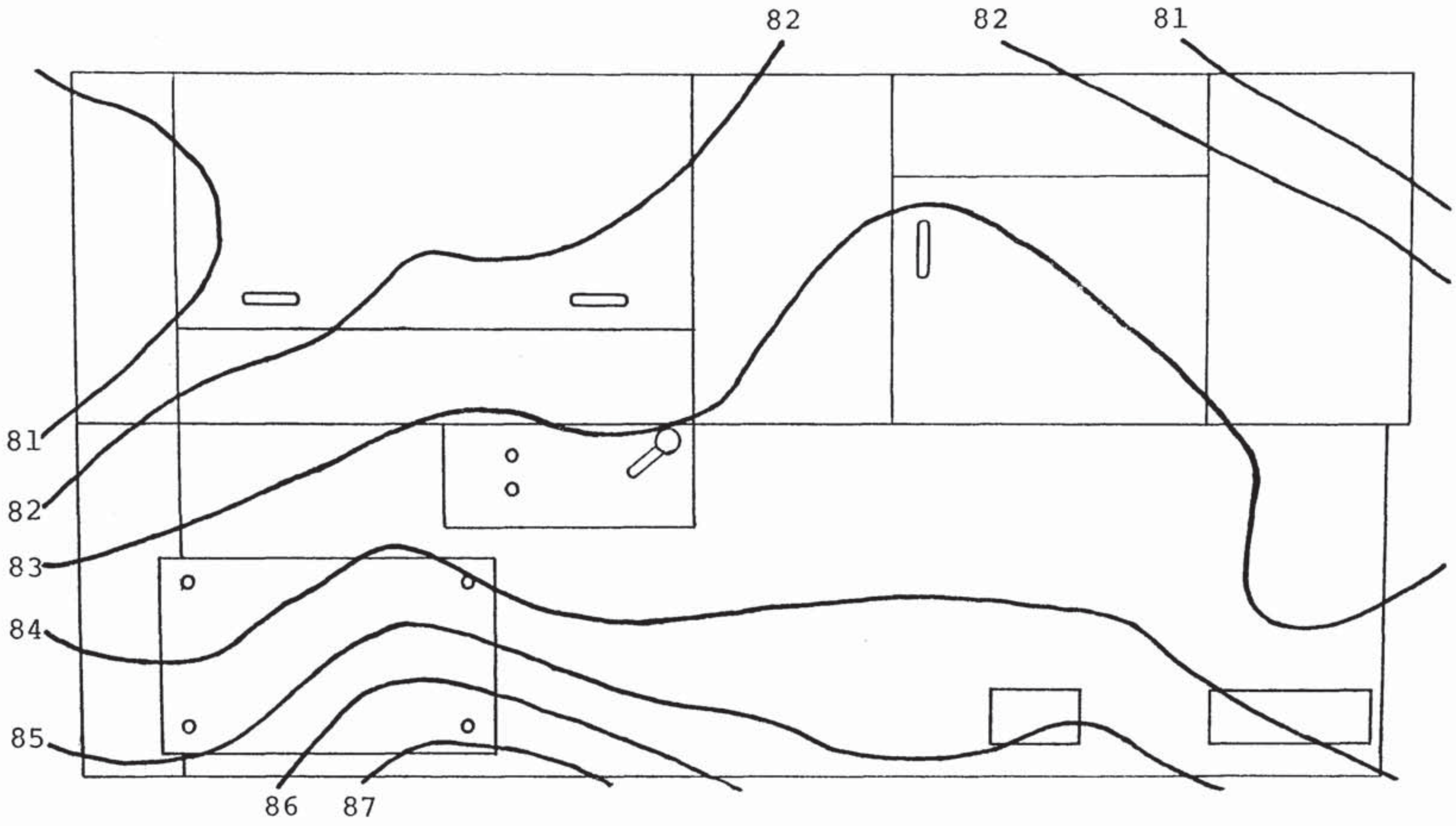


Figure 45

Sound Level at 1 metre from the Back of the Enclosed Strander



Levels in dB(A)

Figure 46

Noise Contours of the Enclosed Strander - Front View

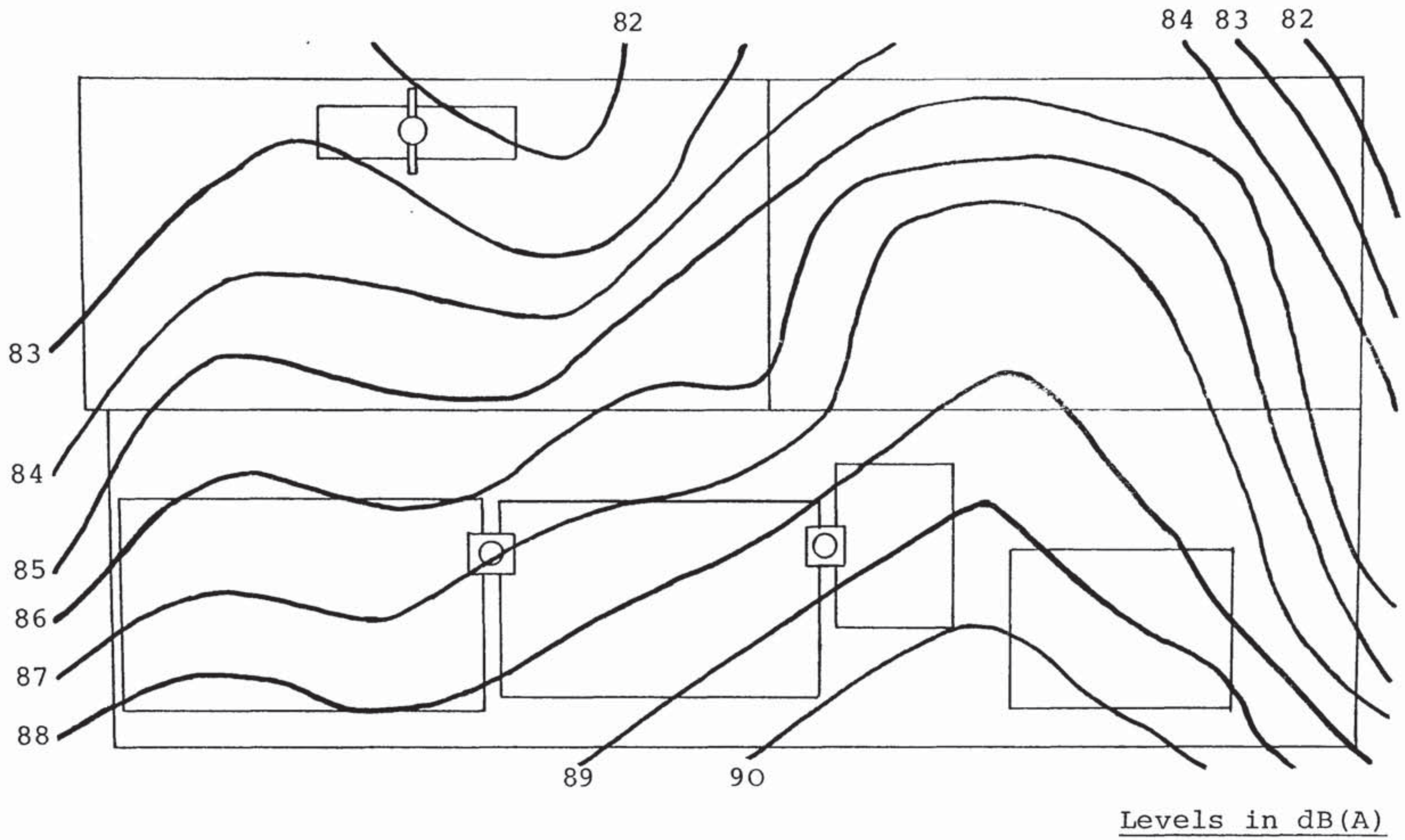
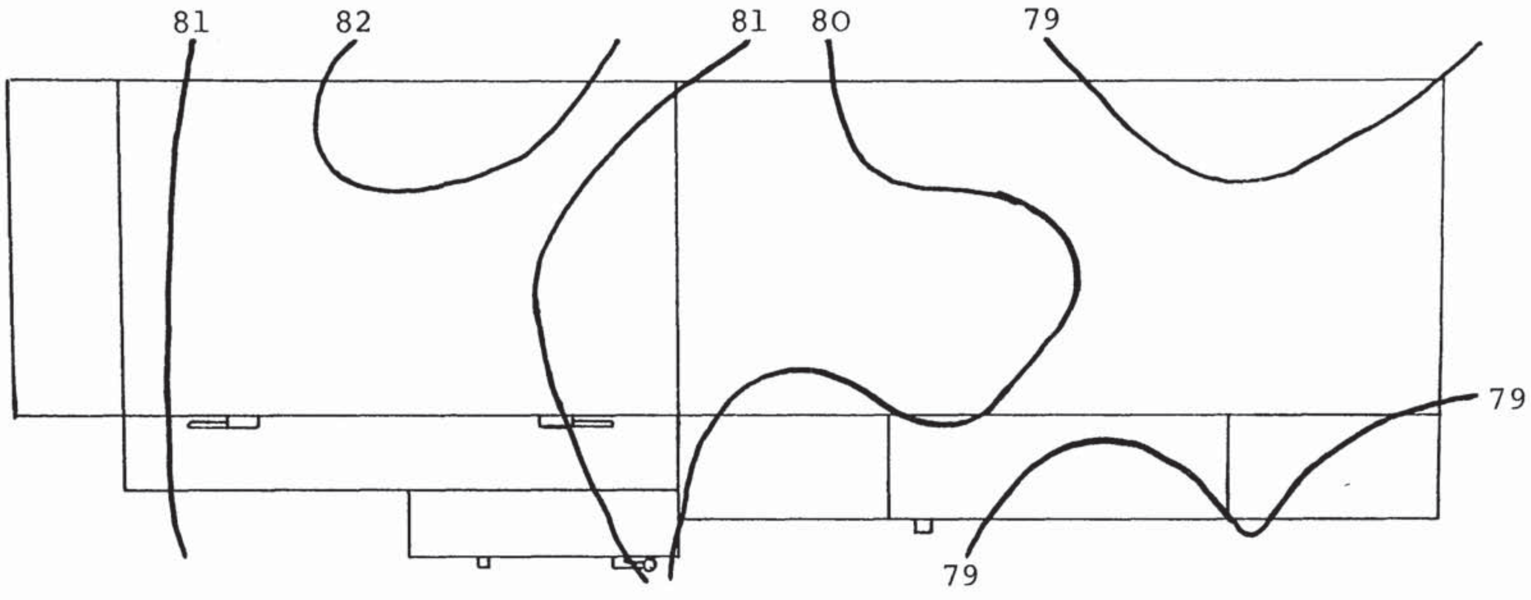


Figure 47

Noise Contours of the Enclosed Strander - Rear View



Levels in dB(A)

Figure 48

Noise Contours of the Enclosed Strander - Top View

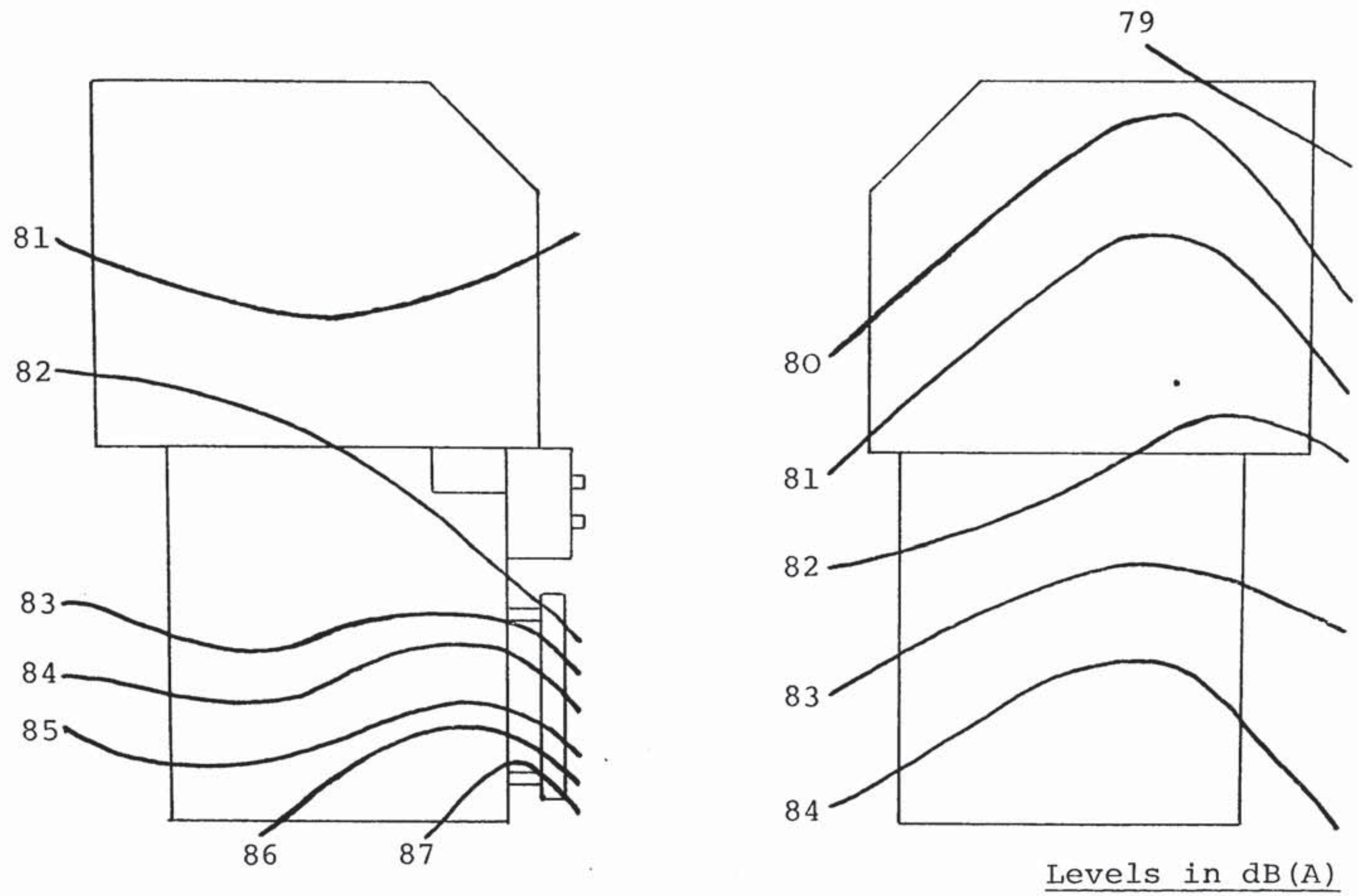
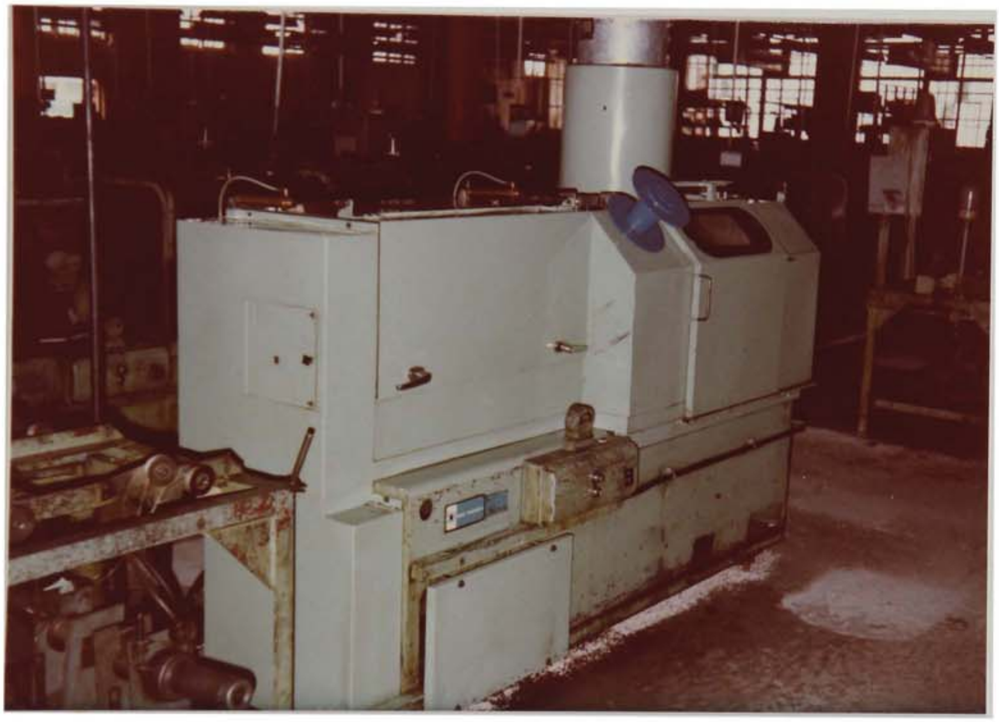


Figure 49

Noise Contours of the Enclosed Strander - End Views unit showed similar increases. Records prove that bearing failure and general mechanical failure is more common during the summer months, and therefore temperature is clearly a critical factor in the maintenance costs of the machines. The power input to the strander was estimated at 4 kwatts, almost all of which has to be lost as heat. Forced cooling was required at the rate of approximately 0.9 m^3/second, and this was achieved using an axial fan mounted on top of the strander at the collection unit end. By constructing a replacement drive cover at the torsion head end a silenced inlet port was produced which allowed air to pass over the whole of the machine before being expelled by the fan through a box silencer. The acoustic performance of the enclosure was found not to be significantly affected by the cooling modifications. The temperature of the machinery inside, however, was in consequence lower than the temperature of stranders without the enclosure.

The silenced prototype strander was moved from the laboratory in the Engineering Development Department to the production site for trials. A single quiet strander made no significant difference to the overall factory noise levels, but the objective was to gauge the reaction of the operators and maintenance staff to the modified machine, and to discover if the design is sufficiently robust to withstand a factory environment. After two months continuous operation Steel Cords ordered a further ten enclosures. At the time of writing the prototype is still operating satisfactorily, and has not suffered undue damage. The management, operators and engineers are more than satisfied with the results.

A picture of the prototype model is to be seen in Photograph 2. The production versions were designed differently in the light of experience and for ease of construction. The detailed design and draughting was the work of a Senior Designer in the Engineering Development Department. If the ten enclosures, sold at a cost of £1,600 each, prove as successful as the prototype, all the 94 stranders will eventually be modified. Plans are already being made to perform a similar noise control exercise on the closing machines, which will lead to the plant noise levels being reduced to less than 90 dB(A) throughout the factory.



Photograph 2

Prototype Model of the Horizontal Strander

at Steel Cords

10

Recommendations for Courtaulds' Future Group Policy on Noise

Chapter 10

Recommendations for Courtaulds' Future Group Policy on Noise

10.1 Introduction

Faced with a workforce and legislation increasingly hostile to high noise levels, the textile industry will find itself with a growing liability in the course of the next few years. Substantial sums of money will be directed towards reducing noise levels, and in compensation for damaged hearing. The philosophy guiding the recommendations in this Chapter is that, one way or another, considerable expenditure on noise in the future is inevitable. The objective is to ensure that the resources which Courtaulds will devote to noise problems are effectively spent; that is, to the greatest benefit of the Group and those employees affected by noise.

10.2 Controlling Noise from Existing Installations

Examples of noise source analysis and noise control have been discussed in Chapters 8 and 9. Much can be done to reduce noise in existing plant. There is, however, a common attitude in industry that noise control is too expensive. There are many cases where noise levels could be dramatically reduced at little cost, but the project is never given serious consideration. The chief objective in the section of the Group Standard on Noise relating to existing installations (see Appendix 1) is to persuade managers to give noise control projects a balanced consideration.

There are many cases where noise reduction is not reasonably practicable, having view to financial constraints as used in the Health and Safety at Work Act (see Section 3.6). The Courtaulds Group has a high investment in plant and machinery which exceeds 85 dB(A), but which will not be replaced by newer equipment in the near future. If noise reduction is not reasonably practicable it is important that the Group can show this to be so. The exercise of deciding on the most economical method of achieving the target should be undertaken, and the costs established. Justification for not reducing noise levels can only be made on the basis of this information. If the target level of 85 dB(A) cannot be achieved, partial reduction may be reasonably practicable, perhaps with a programme for further reduction by stages in the future.

The Group Standard on Noise is an opportunity to ask managers to make this initial step. Detailed methods of noise control are not required in this Standard. The source of assistance for noise control is provided. Otherwise the objective of this part of the Standard is to ensure managers make a conscious decision about the possibilities for noise reduction, and do not dismiss it out-of-hand. It is also important to keep a written record of the costs involved, so that the decision can be defended at a later stage if it is challenged by Factory Inspectors or a civil court. The relevant parts of the Group Standard are:-

a) *The most economical method of reducing the noise levels in each area to a level below 85 dB(A) shall be determined . An estimate of the cost shall be prepared and a written record kept. It should be the responsibility of the manager to decide whether the noise control measures are reasonably practicable based on the cost estimate. Where 85 dB(A) is unattainable the maximum reduction in noise which can reasonably be achieved shall be determined. Required modifications shall then be made to the machinery and/or the building.*

b) *If noise reduction is technically possible, but cannot be justified financially, a programme shall be produced to reduce noise levels over a period of time as funds become available, and as machinery has to be renewed.*

10.3 New Installations

In cases where new plant is purchased, or complete new factories are constructed, the planning stage provides by far the best opportunity to ensure noise levels are minimised. It is invariably less expensive to avoid noise problems in the design of buildings or machinery or to purchase a quieter machine, compared with later modifications to buildings or plant. In addition, the cost of noise control is shifted onto the capital cost of the project, instead of having to be found from the operating budget.

The selection and design at the planning stage should include consideration of the resulting plant noise levels, with the objective of ensuring they do not exceed the specified limit of 85 dB(A). If this is not possible, the projected level should be as close to the 85 dB(A) limit as is reasonably practicable. The noise levels in each area of the plant will depend on the following parameters:-

a) The noise emitted by each machine (sound power level) in that particular area of the plant.

b) The number of machines in each area.

c) The positioning of each machine relative to each other, and to the walls.

d) The room size and reverberation characteristics.

If a machine supplier specifies sound emission levels, or the sound level at one metre distance in certain positions under anechoic conditions, it is not a simple matter to relate this to the final noise level in the plant, especially where several machines are present. The combined effect of an array of machines, often found in the textile industry, is considerable. It ranges from a little more than an extra 3 dB above the single machine level in cases where long frames stand facing each other in pairs with a gangway for an operator between, to around 7 dB in highly reverberant factories. To be certain of meeting the 85 dB(A) criterion for an array of machines, a single machine would have to have a noise specification not exceeding 78 dB(A) at the operator's position.

A single machine level of 78 dB(A) is difficult to achieve where reciprocating and rotating mechanisms are employed. Each case should be judged on its merits, and detailed calculations should be made to determine the predicted noise levels. It is important that an acoustic specialist is consulted at an early stage of the planning for the new installation, or in the design of the new machine. This is the prime recommendation made in the section of the Group Standard on Noise concerned with new installations (Appendix 1.) As a rule of thumb, single machines should have a specification at least 3 dB less than the required maximum plant levels, if they are to stand alone, to allow for the differing room characteristics and the increase in noise level with age. If the single machines are to stand in arrays, the specification for each should not exceed 7 dB below the required maximum plant level.

In circumstances where noise levels are going to exceed the 85 dB(A) limit, the Group Standard should state that the tendering for plant and equipment can only proceed with the written authority of a Main Board Director.

10.4 <u>Circulation of the Group Standard on Noise</u>

The Group Standard on Noise has been discussed in draft form in preceding chapters and referred to the two preceding sections. The main categories of the Standard are:-

1. A maximum noise limit

2. Noise surveys

3. Controlling noise from existing installations

4. New installations

5. Environmental noise

The draft Standard developed from discussions of a working party, included the Courtaulds Group Deputy Chief Medical Officer, and the Head of the Group Safety Department. The above sections of the draft were prepared by the author of this report. The Standard will also include sections on hearing protection and audiometry, and information on who to consult on all aspects of noise control and hearing conservation within the Group and outside.

The purpose of the Group Standard is to complement the 1972 Code of Practice [7] and other publications. A bibliography is therefore also included. Managers will be expected to read the Code of Practice and be aware of their responsibilities under the law. The Group Standard provides a brief summary of the legal requirements, and is written with the processes found in Courtaulds in mind. It is hoped that the widespread circulation of the Standard will be of assistance to factory managers in dealing with noise problems. In particular, the Standard makes clear the sources from which advice can be sought.

It should be clear that the Standard has the full backing of the Main Board of Courtaulds, and that the recommendations within the Standard are company policy.

For this reason it is proposed that the final edition should carry a foreword by the Main Board Director responsible for safety, commending the Standard to managers throughout the Group.

The implementation of the recommendations will be the responsibility of the Safety Officer on each site. The central safety co-ordinating body, the Group Safety Department at Coventry, will therefore have a crucial role in encouraging the use of the Standard, and in training the safety officers in noise measurement and hearing conservation.

It will be a long process persuading all parts of the Group to accept the need to tackle noise problems, and even longer before the recommendations are complied with. The introduction of legislation will provide a major incentive to reduce noise levels. If the existance of the Standard is known throughout the Group prior to legislation, resources will not be wasted in sudden, panic action in attempts to meet the legal requirements.

10.5 Noise Control Unit

There should be, within the Courtaulds Group, a single body specialising in all aspects of noise control and measurement. If the Group's expertise and instrumentation were concentrated in one department, duplication of equipment would be avoided, and there would not be the need to train such a large number of persons in noise control. In short, the problems of noise could be dealt with more efficiently.

The specialist noise unit would offer advice on a consultancy basis. Each manager in the Group would know where to look for advice. It should be sited in a central department, so that it is not tied to one particular division of the Group. The alternatives are: the Group Safety Department, the Group Medical Department, the Pollution Control Unit or the Engineering Development Department. The Pollution Control Unit is presently staffed by qualified chemists, and concentrates on chemical pollution. The Group Safety and the Group Medical Departments are already concerned with the effects on hearing of noise problems, and will both inevitably be involved in the future. The constant liaison between Group Safety and the Site Safety Officers throughout the Group means training and the dissemination of information, such as the Group Standard, should be made through that Department. Advice on the clinical aspects of hearing loss and the interpretation of audiometric measurements is firmly the responsibility of the Group Medical Department.

The bulk of the Groups involvement in noise will be in engineering or sound level measurement. The techniques of noise control require an understanding of the way in which machines operate, and the process of noise generation, transmission and radiation. Sound analysis equipment, other than the simple sound level meter, is sophisticated, and trained technicians are required for its correct operation. The Engineering Development Department has had experience in noise measurement and control over a period of many years. The Department already owns frequency analysis, statistical analysis and vibration measurement equipment.

It is important for managers to know where specialist advice and assistance is available and it is proposed that a Noise Control Unit should be established in the Engineering Development Department. The chief functions of the Unit envisaged are:-

1. Surveying noise levels inside factories when requested to do so by local management. Regular monitoring could be carried out for sites not having their own equipment. The Unit would help managers comply with the Noise Survey section of the Group Standard (see Chapter 4.)

2. Checking measurements made by Inspectors and

Local Authorities when they become involved as required by the Health and Safety at Work and Control of Pollution Acts.

3. Advising on noise control methods appropriate to specific cases. Conducting analysis and tests to be able to give accurate advice.

4. Designing hardware for reducing noise from existing machines.

5. Advising on the design of new machinery and buildings constructed by the Group, in order to ensure noise problems are minimised.

6. Assessing the specifications of new machinery to be bought-in by the Group, to ensure it will not give rise to further noise problems.

7. Providing expert advice to the Group Legal Department on claims which arise from hearing loss.

8. Advising plant managers on technical aspects of noise when disputes arise with employees and unions.

Vibration measurement and the balancing of rotating parts in machinery are closely related to the functions described above. In particular, the same instrumentation is used to measure vibration and noise. The Noise Control Unit could therefore take responsibility for related areas in addition to noise.

The policy of the Engineering Development Department is to make a charge, where possible, to the division within the Group for which the research or development is being performed. This would be the case for research on specific machines, which would be costly and long-term. Surveying and advice, which are relatively short unspecific exercises however should be financed centrally because if factory managers are obliged to pay for a simple noise survey and a report giving advice on action they should take, there is an unfortunate disincentive for them to initiate the request for assistance. In addition, some of the work which may eventually be undertaken by the Unit, such as developing a Hearing Protection Programme (discussed below), would not be directly attributable to a single division.

The Noise Control Unit would commence with one graduate noise specialist. The level of work would build up as the Noise Control Unit became known through the Group, particularly following the circulation of the Group Standard. A technician would soon be required to carry out the routine analysis in the laboratory, and to assist with balancing and standard noise surveys. During the launching of the Noise Control Unit, by continuing current projects, 50% of the time could be charged at £12 per hour to divisions, and therefore recovered by the Department. This proportion can be expected to grow to 75% with a staff of two, once the unit is established. The remainder, in the first instance, would be required for setting-up the Unit, and later for assisting with training and the development of a hearing protection programme.

10.6 Training

It is not the intention for the Noise Control Unit to be consulted on all noise control problems throughout the Group. This would be impossible as well as impracticable. There is a need for selected personnel throughout the Group to be trained in the fundamentals of acoustics, noise measurement and noise control. The courses would be essentially practical with a minimum of acoustics theory. They would concentrate on providing simple, but certain, engineering solutions to specific types of problem.

There is a wide range of people who would find such courses useful:-

a) Site Safety Officers. They would be interested in methods of noise measurement, and in their responsibilities under the Health and Safety at Work Act[8]. They would also be concerned with methods of hearing protection, and operating a hearing conservation programme.

b) Works Engineers. A course for them would clearly concentrate on the sources of noise in the types of machinery they use, and the methods by which it is radiated. There would also be a comparison of the alternative approaches to quietening machinery, pointing out the pitfalls and relative costs of each.

c) Purchasers. Those responsible for purchasing machinery and plant need to understand noise emission levels which are often quoted in specifications today, and the implications these have for the environment in which they are to be used.

d) Designers. There are a number of units throughout the Group which design and construct their own machinery, mainly for use in the Group. It is essential they are educated to consider the noise emission of a proposed machine while it is still at the design stage.

e) Managers. They will be concerned with their responsibilities under the Health and Safety at Work Act, and the Control of Pollution Act [27]. Managers who find they have to negotiate with Factory Inspectors, Unions or the local authority will wish to become familiar with the significance of noise levels.

Group Safety Department already organise many courses for Safety Officers on all aspects of safety. Courses specifically on noise would best be organised by the same department. The whole course could be handed over to an outside body, such as Sound Research Laboratories [35], but it is hoped that there will soon be sufficient expertise within the Group to principally use speakers from within the Group.

10.7 Hearing Conservation

The importance of reducing the incidence of hearing loss amongst Group employees as a result of them working without hearing protection in high noise areas has already been discussed (Chapter 5). A dramatic increase in the proportion of employees wearing protection is the most immediate and important requirement in the field of noise at present. Each factory in the Group, which has a significant number of employees working in 90 dB(A) or more without actually using hearing protection, should be pressed to draw up a hearing conservation programme.

Managers must realise that they cannot avoid responsibility by merely pinning notices to walls and providing ear muffs. They must motivate their workers to adopt the habit of wearing proteciton, and make the process continuous so that they do not lapse. The motivation would be provided by several aspects integrated together to form a hearing conservation programme.

a) Training. Many workers are not aware of the damage noise can do to their hearing, and to spell it out would provide sufficient incentive to many. Noise as a hazard is not as apparent as many industrial safety hazards. There are films which can be hired to put over the message, and visiting speakers could be used.

b) Providing a Choice. Hearing protection is uncomfortable, but many people find one type much better than another. If a choice of protection is provided the discomfort is minimised.

c) Factory Rules. The most successful factories in the Group in the use of protection are those where the manager takes a firm stand and insists hearing protection is used.

d) By Example. If managers, staff and visitors do not wear protection when they walk about the factory, operators are unlikely to take the matter seriously. They will not appreciate the subtleties of exposure duration, but will follow their managers example.

e) Factory Nurse. If the Medical Department takes every opportunity to emphasise the hazards of noise and the value of hearing protection, employees will understand that it is not a petty matter.

f) Safety Officer. Imaginative schemes by the Safety Officer could provide important motivation. For example, competition between shifts for the highest proportion of operators using hearing protection.

Persuading people to change the habits of a working lifetime and wear unpleasant protection is very difficult. It is also important to ensure the protection is correctly used (Section 5.2), and this would be a major aspect of the training. Experience in other industries, and in some factories in the Group, shows that it is possible to persuade the vast majority to protect themselves from noise.

10.8 Conclusions

The recommendations and observations made in the earlier parts of this chapter and throughout the thesis have developed during the course of the project. Many of the proposals have already been approved, and are being implemented. The noise control projects discussed in this thesis are continuing and being extended. The services which have been additionally offered by the Engineering Development Department are expanding, and the facilities will shortly be advertised as a Noise Control Unit. The draft Group Standard on Noise is to be discussed, and will be widely circulated. The next stage is to persuade the Main Board of the importance of Hearing Conservation Programmes in the Group's factories, and to find methods of encouraging and guiding managers to do so. A Noise Control Unit is being establised in E.D.D., and it will be responsible for noise and vibration work throughout the Group on a consultancy basis. There is a real demand for a service of this kind, reflecting the increasing concern in the Group about noise. The work which was started in this project will continue, and experience gained by it will be a valuable asset in Courtaulds future.

Appendices

1. Proposed Group Standard on Noise.

2. Noise Levels at Courtaulds, Hosiery Limited, Langley Mill.

3. Extract from Report EDD 1400 : "Exposure to Noise While Working in the Courtelle Plant at Grimsby"

References

Appendix 1

Proposed Group Standard on Noise

1. Noise Surveys

Noise surveys shall be made if it is suspected that noise levels may exceed 85 dB(A) in any area. They shall be performed by a person who has been trained in methods of noise measurement. Surveys shall be repeated at regular intervals, or if there is a change in the conditions of the machinery in that area.

1.1 Instruments

Noise measurements shall be made with a sound level meter which conforms with B.S. 3489 (industrial grade) or with B.S. 4197 (precision grade).

The meter shall be calibrated before and after each set of measurements. The calibration shall be by a sound source of known magnitude applied to the meter. The meter shall be adjusted to read correctly the sound level of the calibration source. The level, together with the weighting network used shall be recorded. At the end of each set of measurements the calibration source shall be reapplied, and the reading recorded before any adjustment is made. All calibration readings shall be made as accurately as the scale will allow without correction to the nearest whole decibel.

The condition of the batteries in both meter and calibration source shall be checked before and after each set of measurements in accordance with the manufacturers instructions.

The meter shall normally be used in the "slow" mode. The noise levels shall always be measured using the 'A'-weighting network, and readings quoted in units of dB(A).

The noise level shall be read to the nearest whole decibel. If the noise level fluctuates rapidly by up to $\pm$ 2 dB(A) the average reading shall be estimated by eye.

Conventional sound level meters are not suitable for measuring noise levels which fluctuate by more than $\pm$ 2 dB(A), or which fluctuate slowly over a period of one minute or more. An L_{eq} meter shall be used instead to measure equivalent continuous noise level.

Impulsive sounds, such as hammer blows, are also not accurately measurable by conventional sound level meters. An impulsive sound level meter shall be used.

1.2 Measurement Positions

Noise levels shall be measured on all positions where employees may work in the course of their duty. The position of the sound level meter shall be:-

a. At a height of 1.5m from the ground if a person normally stands at that position, or 1.2m if he normally sits.

b. With the microphone directed towards the greatest sound source.

c. If a machine is nearby, the noise level may vary considerably as the meter is moved. The meter shall be held as close to the machine as the operator normally puts his head.

d. The spacing between measurement positions shall be sufficiently small to accurately predict the noise level between the chosen positions. Very few readings are required in a room where noise levels are fairly constant.

1.3 Personal Noise Dose

Employees exposed to their maximum noise level for less than six hours each day will receive a noise dose significantly lower than they would for eight hours a day. An equivalent continuous noise level (L_{eq}) should be calculated. This applies particularly to persons moving from one area to another.

The method of calculating L_{eq} is given in Appendix 3 of the Code of Practice[7].

Unless L_{eq} is calculated, any person exposed to an excessive noise level for any period shall be considered at risk, and hearing protection shall be used during the period of the exposure.

1.4 Noise Survey Report

Recorded noise levels shall be accompanied by the following information:-

a. The name of the person carrying out the noise survey, and the date of measurement.

b. A plan of each room where appropriate, with all machines and measurement positions marked.

c. An indication of which machines were in operation at the time of the survey.

d. The height of the meter above the ground.

e. The distance from microphone to machine if the measurement position is close to it.

f. Type of sound level meter used.

g. The settings on the sound level meter, and calibration information as defined above.

h. L_{eq} if calculated.

i. The number of persons normally employed in the area.

j. Any other prevalent conditions which would enable the measurements to be repeated at a later date, such as machine loading or machine speeds.

2. Excessive Noise Levels in Existing Installations

2.1. Maximum Noise Level

The maximum level of noise in which employees work should be 85 dB(A), or the equivalent L_{eq}. If a feasibility study shows 85 dB(A) is unattainable, the maximum reduction in noise which can reasonably be achieved shall be determined. A written record of costs shall be kept on file if reduction to 85 dB(A) is not reasonably practicable.

A programme for further noise control shall be produced, indicating the expected reductions as funds become available. Wherever possible, the maximum level of 90 dB(A) recommended in the Code of Practice[7] shall be met.

2.2. Hearing Protection

Hearing protection shall be worn in all noise hazardous areas where the level exceeds 85 dB(A), either because reduction is not possible or until it is achieved.

3. Noise in New Installations

The following procedure shall be followed during the planning of a new installation:-

a. Consultation should take place at the proposal stage with a central department with Noise Control expertise.

b. Noise levels from a single machine should not exceed 85 dB(A) in the environment in which it is to operate.

c. The noise level of arrays of machines, and their positioning, should be such that the calculated accumulation of noise does not exceed 85 dB(A) at any point.

d. In circumstances where noise levels are going to exceed the above levels, the tendency for plant and equipment can only proceed with the consent of a Main Board Director.

4. External Noise

The following is a guide to the Company's responsibilities under the Control of Pollution Act, 1974, reference must be made to the Act for a complete statement.

4.1. Complaints from the Public

The local authority are required to investigate a complaint, even if it is made by a single person. In addition, local authorities should inspect their area.

Section 58 describes the action they are empowered to make:-

58.-(1) Where a local authority is satisfied that noise amounting to a nuisance exists, or is likely to occur or recur, in the area of the local authority, the local authority shall serve a notice imposing all or any of the following requirements:-

(a) requiring the abatement of the nuisance or prohibiting or restricting its occurrence or recurrence;

(b) *requiring the execution of such works, and the taking of such other steps, as may be necessary for the purpose of the notice or as may be specified in the notice;*

and the notice shall specify the time or times within which the requirements of the notice are to be complied with.

58.-(3) The person served with the notice may appeal against the notice to a magistrates' court within twenty-one days from service of the notice.

58.-(4) If a person on whom a notice is served under this section without reasonable excuse contravenes any requirement of the notice, he shall be guilty of an offence against this part of this Act.

58.-(5) In proceedings for an offence under the preceding sub-section in respect of noise caused in the course of a trade or business, it shall be a defence to prove that the best practicable means have been used for preventing, or for counteracting the effect of, the noise.

72.-(2) In that expression (best practicable means) *"practicable" means reasonably practicable having regard among other things to local conditions and circumstances, to the current state of technical knowledge and to the financial implications.*

4.2 Noise Levels Likely to Cause a Nuisance

It is impossible to define a maximum noise level which noise from a factory should not exceed. It depends on the background noise in the area of each particular factory. BS 4142 provides a method of calculating whether a certain noise level is likely to provoke complaints.

In general, if the noise from a factory can be clearly heard above the background noise while standing outside the complainants residence, either at night or during the day, the local authority will agree that a nuisance exists.

4.3. Sources of Noise

Roof or wall mounted extractor fans are a common source of noise causing complaint. They are often quietened using a proprietary in-duct silencer.

Noise from machinery inside a factory often breaks out from weaknesses in the fabric, such as doors and windows. Special acoustic doors, double glazing or simply better edge seals may provide sufficient reduction. Ensuring doors and windows are kept closed at night may also prevent complaints.

Reducing the level of noise inside the factory will reduce noise outside by a corresponding degree as well as improving conditions inside.

4.4 New Installations

All new factories must conform to noise criteria which ensure that noise complaints are unlikely. Expert advice shall be taken at the planning stage to predict noise levels outside the factory boundary, and to recommend optimum methods of construction.

4.5 Noise Abatement Zones

Local authorities are expected to introduce "noise abatement zones." If an area is to be made a noise abatement zone, the local authority will measure the level of noise emanating from premises within the zone, and record the measurements in a register.

The owner and occupier of the relevant premises are served with a copy of the level of noise recorded on the register, and they may then appeal within twenty-eight days against the record.

The level of noise recorded in the noise level register in respect of any premises shall not be exceeded except with the consent in writing of the local authority.

Appendix 2

Noise Levels at Courtaulds Hosiery Limited, Langley Mill

Introduction

At the request of Mr. Colin Mee a survey was made of noise levels at the Langley Mill site of Courtaulds Hosiery Limited. A Bruel and Kjaer Precision Sound Level Meter (type 2203) fitted with an octave band filter set (type 1613) and one inch condenser microphone (type 4145) was used. It was calibrated before use, and the calibration checked after measurements were completed. Overall noise levels were measured across the whole audio frequency spectrum using the 'A'-weighting network and units of dB(A). Octave band levels, which show the distribution of frequencies, were measured in dB (linear) and include the frequency range contained in the octave centred on the specified frequency. The meter was set in the "slow" position and levels read to the nearest whole decibel.

In all measurement positions the meter was held at a height of 1.5m above the ground, which is approximately the height of a standing operator's head.

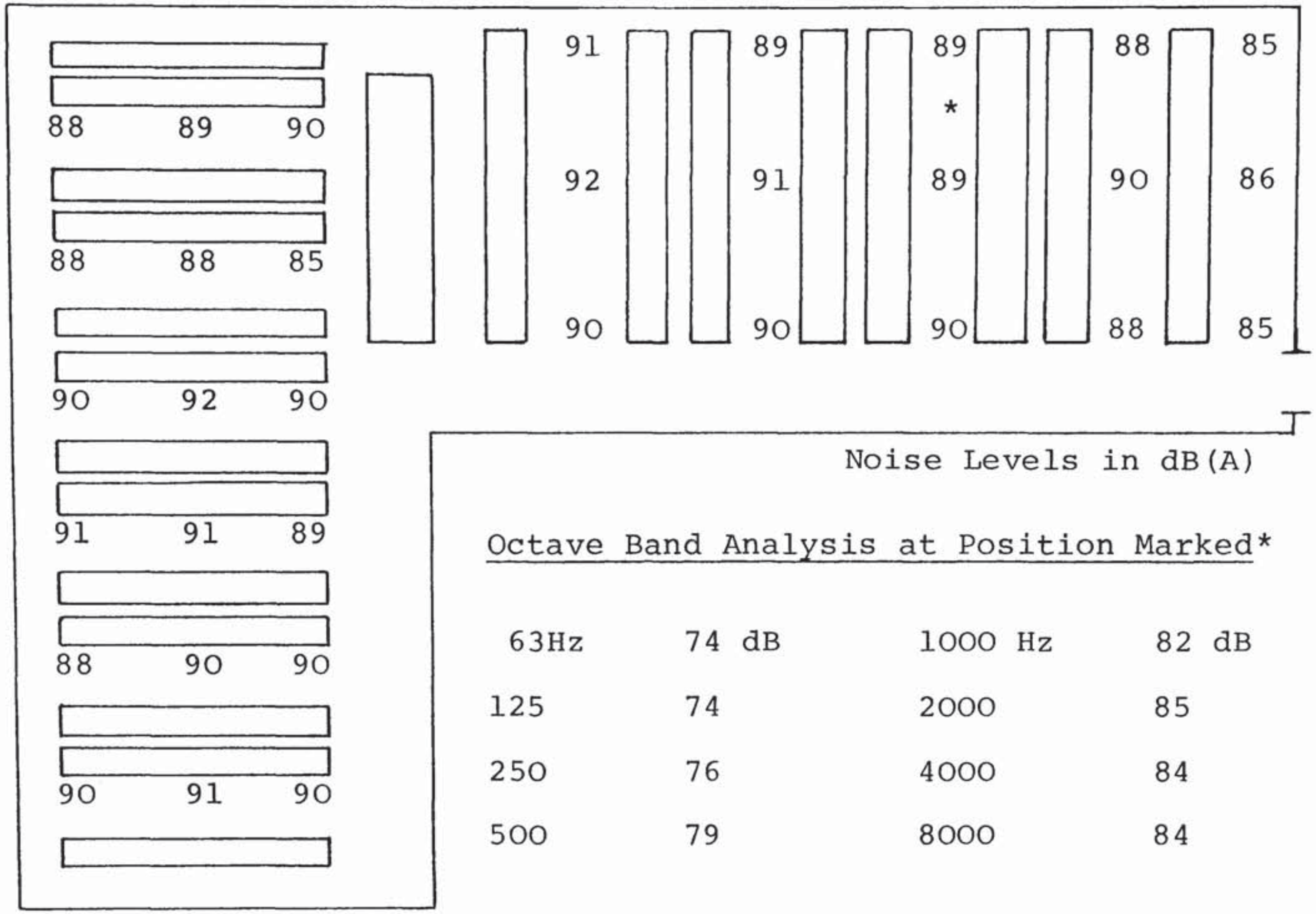
Noise Levels

The following is a summary of the measurements recorded. The detailed noise levels in each area are shown in Figures 50 to 54.

Area	Range of Noise Levels in dB(A)
Fully Fashioned Knitting	88 - 92
Top Floor Seam-Free	87 - 92
Middle Floor Seam-Free	88 - 91
Seam-Free T.S.T.	87 - 94
Fully Fashioned T.S.T.	80 - 91

In the three knitting areas the noise levels were measured at the normal operator position between the banks of machines. In the seam-free knitting areas some banks of machines were not in operation. Although noise levels between such banks were not measured, levels in adjacent rows will have been slightly lower as a result of the idle machines.

In the turn-seam-turn areas (T.S.T.) the noise levels were measured in the passageways, at a distance of between 1.0 and 1.5 metres from the sewing machines, and not at the operators ear position. At the position marked by an asterisk in Figure 53 in the T.S.T. Seam-free area the equivalent continuous noise level (L_{eq}) was measured since the instantaneous noise level fluctuated. An L_{eq} of



Octave Band Analysis at Position Marked*

63Hz	74 dB	1000 Hz	82 dB
125	74	2000	85
250	76	4000	84
500	79	8000	84

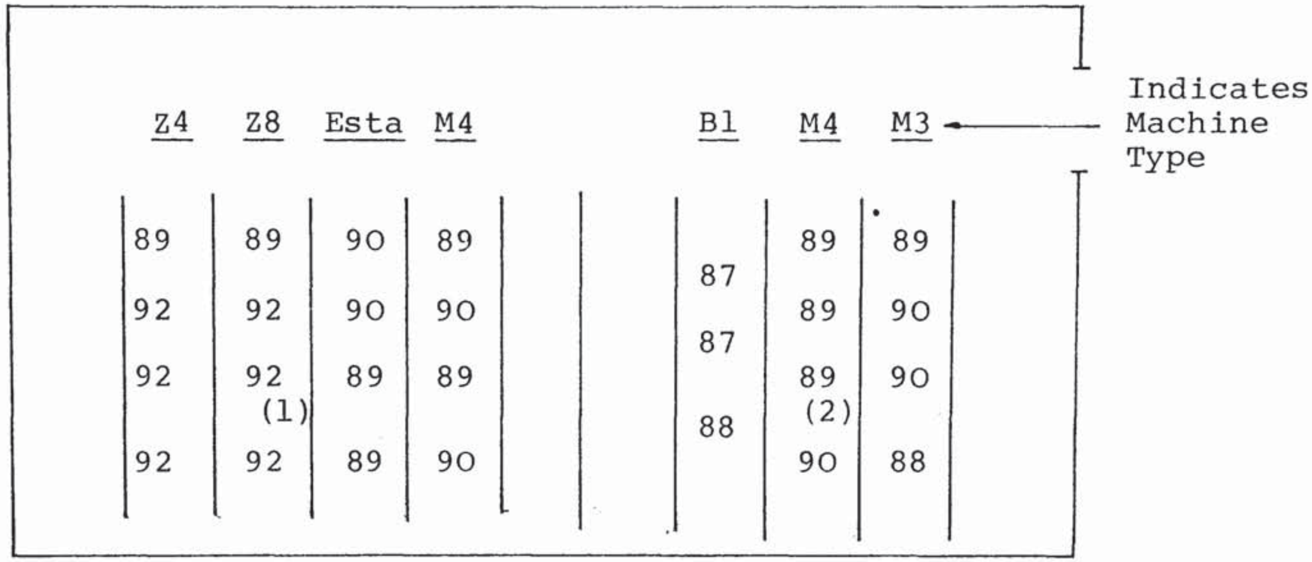
Figure 50

Fully Fashioned Knitting

Octave Band Analysis

at Positions (1) & (2)

Frequency (Hz)	Noise Level (dB) (1)	Noise Level (dB) (2)
63	79	84
125	78	75
250	88·3	83
500	88·5	88
1000	89	85
2000	80	82
4000	75	80
8000	71	75



Noise Levels in dB(A)

Figure 51

Top Floor Seam-Free

Octave Band Analysis

at Positions (1) & (2)

Frequency (Hz)	Noise Level (dB) (1)	Noise Level (dB) (2)
63	77	77
125	77	77
250	83	78
500	89	89
1000	86	83
2000	84	81
4000	81	78
8000	76	75

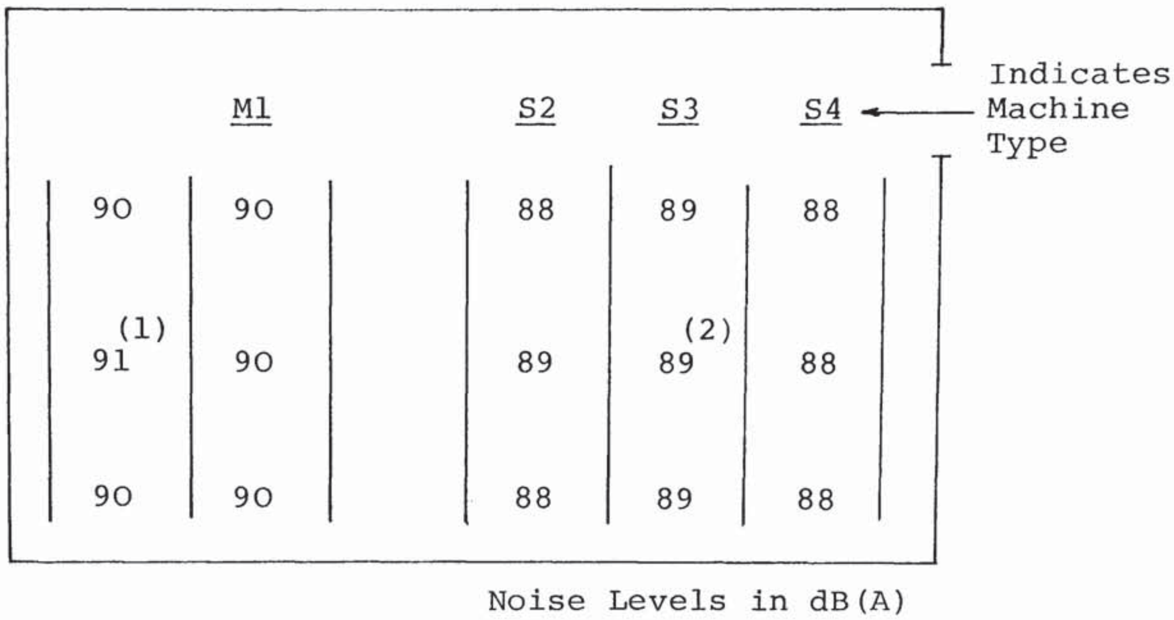
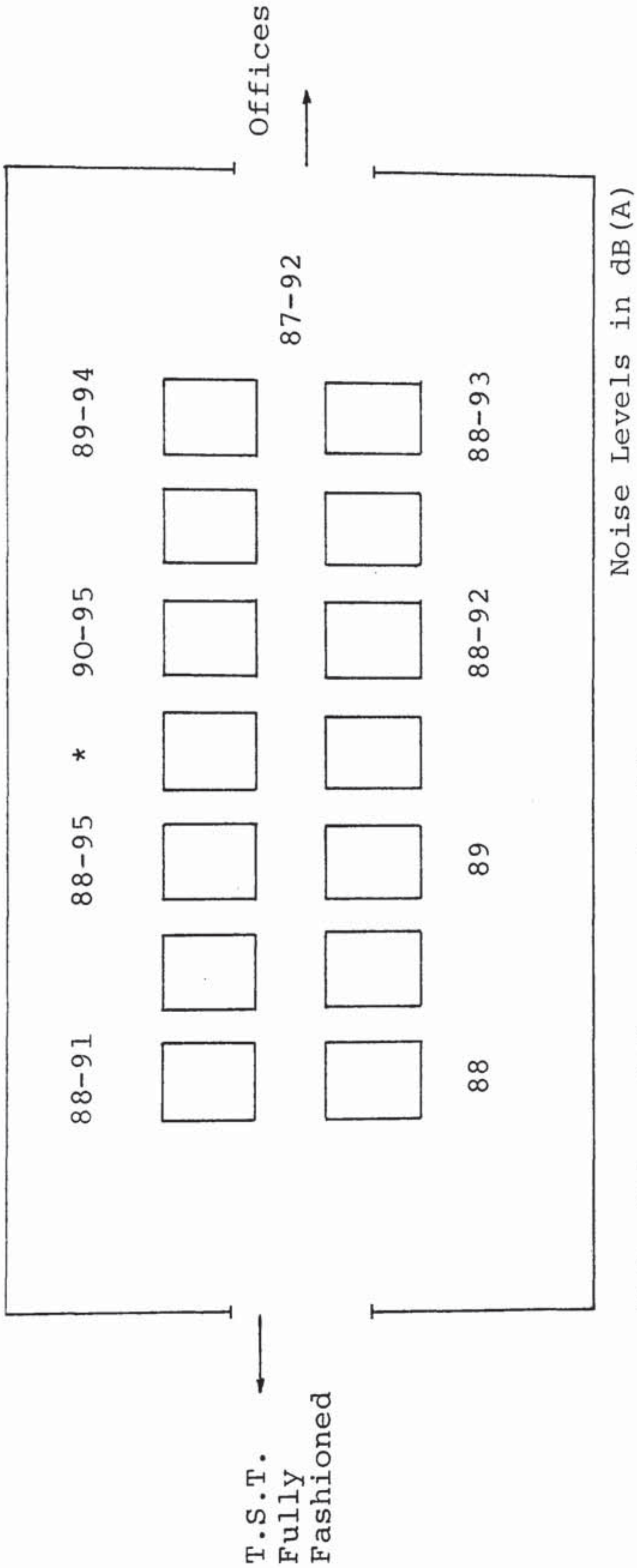


Figure 52

Middle Floor Seam-Free



* Position of Measurement of L_{eq}

<u>Figure 53</u>

<u>T.S.T. Seam-Free</u>

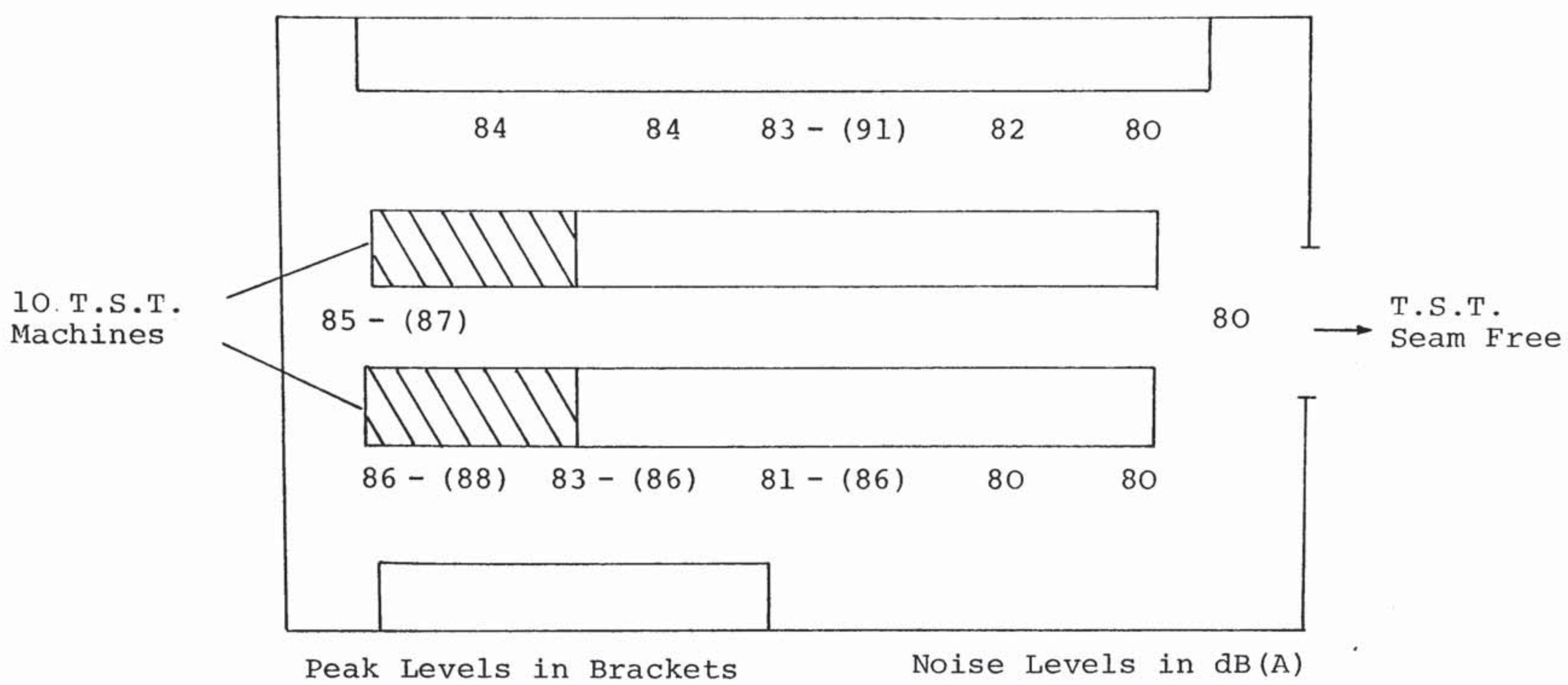


Figure 54

T.S.T. Fully-Fashioned

94 dB(A) was calculated from twelve measurements over the course of one minute.

Octave band levels were measured in one or two selected positions in the knitting areas. The recorded levels are shown beneath the relevant figure.

Discussion

The "Code of Practice for Reducing the Exposure of Employed Persons to Noise" H.M.S.O. 1972 states that:-

> 4.2.1 People should not be exposed to sound levels exceeding the limit set out in 4.3 to 4.5 below unless they are using ear protectors which effectively reduce the sound level at the users ear to or below the limits for unprotected ears.
>
> ....
>
> 4.3.1 If exposure is continued for 8 hours in any one day and is reasonably steady the sound level should not exceed 90 dB(A).
>
> 4.4.1 If exposure is for a period other than 8 hours, or if the sound level is fluctuating an equivalent continuous

level (L_{eq}) may be calculated and this value should not exceed 90 dB(A).

....

4.5.1 In certain circumstances, for example where employed persons move from one area to another, it may be difficult to measure and control exposure to non-continuous sound. If the non-continuous exposure cannot be adequately measured, and controlled, any exposure at a sound level of 90 dB(A) or more should be regarded as exceeding the limit and requiring the use of ear protectors.

The exposure of persons in the T.S.T. areas is excessive, certainly for those working on the T.S.T. machines themselves, and probably also for the others in part of the Fully Fashioned area. They would have to be exposed for considerably less than 4 hours each day to the current noise levels in order to achieve an L_{eq} of less than 90 dB(A).

Although many parts of the knitting areas are below 90 dB(A), section 4.5.1 of the Code of Practice requires the areas to be regarded as if they were above 90 dB(A) unless it can be shown that the exposure of the employees is less than 90 dB(A). This would require a detailed study of the time spent in each position by each operator during a typical day so that the personal noise dose can be calculated.

In the meantime the knitting areas should comply with section 5.2 of the Code of Practice. The T.S.T. areas should comply with this section until noise levels can be reduced below an L_{eq} of 90 dB(A).

5.2.1 Areas where persons may be exposed to sound levels exceeding the limits set out in section 4 should be clearly identified as ear protection areas, and the boundary clearly defined.

5.2.2 Entry to ear protection areas should be restricted to those authorised to do so. All such persons should use effective ear protection.

5.2.3 A prominent warning notice banning unauthorised entry, and entry without the use of ear protection should be posted at every entrance to the ear protection area. ....

Ear Protection

There are many types of ear protection devices available. "Bilsom Propp" eardown dispensed from wall mounted containers is adequate for noise levels encountered at Langley Mill. It is recommended that operators should have the choice of either eardown or the more effective ear muffs. Specialist medical advice on the use of ear protection may be obtained from Group Medical Department.

"Bilsom Propp" is available from Bilsom International, P.O. Box 56, Henley-on-Thames, Oxfordshire. Tel: 049-12-4288.

Conclusion

To comply with the recommendations of the "Code of Practice for Reducing the Exposure of Employed Persons to Noise" H.M.S.O. 1972 all knitting areas and the T.S.T. areas should be designated as ear protection areas, and entry to those areas restricted to those using ear protection.

Appendix 3

Extract from Report E.D.D. 1400: "Exposure to Noise While Working in the Courtelle Plant at Grimsby"

Measured Noise Levels

The noise levels measured in the different parts of Unit IV are:-

a. Spin Deck

A total of 66 measurements were made at evenly spaced positions on the spin deck on Unit IV. The readings are shown in Figure 55. Assuming an operator spends an equal time in each position the equivalent continuous noise level is 87.5 dB(A).

b. Dryer Area

The central position between the dryers of lines L and M had a steady noise level of 85 dB(A). This increased to 87 dB(A) at the rear of line M dryer. However, a typical value for the Spinning Auxilliary working in the area of the dryers would be 85 dB(A).

c. <u>Tow Washing Area</u>

Noise Levels in the tow washing area were a steady 83 dB(A).

d. <u>Others</u>

Control room	74 dB(A)	
Carton make-up area	80 dB(A)	close to hydraulic pump
Dry finish area	78 dB(A)	
Laboratory	62 dB(A)	
Neochrome tank	87 dB(A)	

<u>Work Study Data</u>

The work study data for Unit IV was used to estimate the time spent by Mr. H in each area. The total job specification for a spinning auxilliary given by the work study sheets accounts for a total of 6 hours 17 minutes. The proportion of time allocated to each area is shown in the first column of Table 21.

The work study times should be used as an indication of the proportion of time spent in each area, according to the Work Study Department. The timings in the first column are therefore increased by 17% in the second column to give the shift time, and to the table is added the 40 minutes taken for breaks to make a total for the shift of 8 hours.

The third colum of figures in Table 21 shows the noise levels measured on Unit IV. The shift timing and the noise levels are combined to give an 'f' value in the fourth column.

$$f = \frac{t}{8} \times 10^{(L - 90)/10}$$

Where t is the shift time

The equivalent continuous noise level (L_{eq}) is given by:

$$L_{eq} = 10 \log_{10} f + 90$$

and is in units of dB(A).

The equivalent continuous noise level (L_{eq}) of a Spinning Auxilliary on Unit VI is:

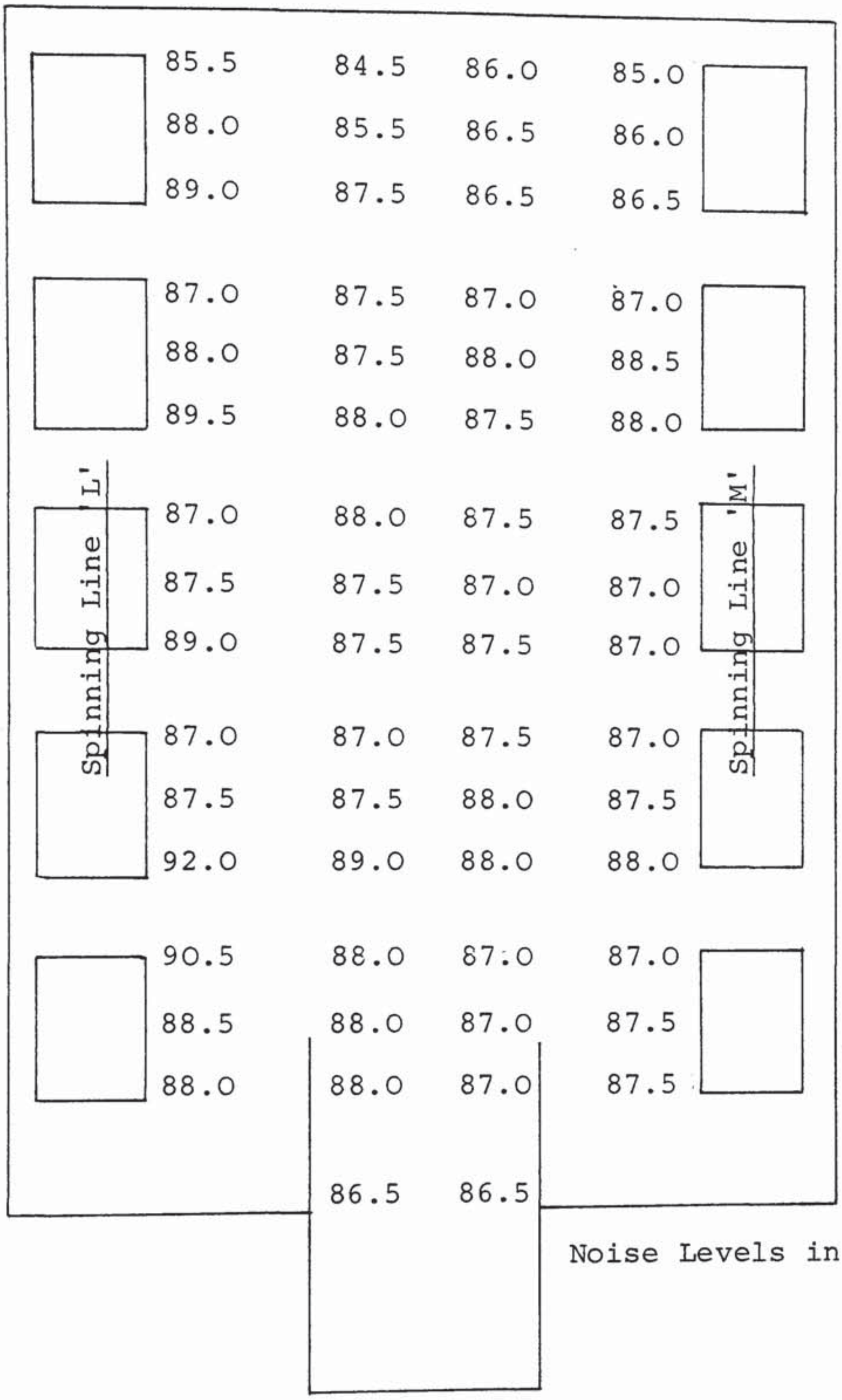
84.6 dB(A)

or 85 dB(A) to the nearest whole decibel

Discussion

Mr. H commenced work in the Plant in November 1965. In July 1974 he was issued with ear muffs after seeing the Works Doctor. He was therefore exposed to the ambient noise levels in the Plant for a duration of about 8½ years. At the time of the audiogram measurements made on the 23 November 1976 Mr. H was 50 years old.

The British Standard 5330 is a "Method of Test for Estimating the Risk of Hearing Handicap due to Noise Exposure." Exposure to 85 dB(A) for 8½ years corresponds to a noise immission level of 94 according to BS.5330. Such a noise immission level can be expected to cause hearing loss of 30dB (mean of 1 ,2 and 3KHz) in 1% of cases for a person aged 50. The risk of developing hearing loss to the extent measured (46dB in the right ear, and 39 dB in the left ear) in Mr. H as a result of his employment with Courtaulds Limited is less than 1%.



Noise Levels in dB(A)

Figure 55

Noise Levels on the Spin Deck, Unit VI

	Work Study Time (Seconds)	Shift Time (Hours)	Measured Noise Level dB(A)	'f' Value
Spin Deck	3343	2.28	87.5	0.16
Dryer Area	775	0.25	85.0	0.01
Tow Washing	4600	1.49	83.0	0.04
Pig & Fil	5135	1.66	85.5	0.07
Control Room	3343	1.08	74.0	0.003
Carton Make-Up	752	0.24	80.0	.003
Dry Finish	557	0.18	78.0	.001
Laboratory	345	0.11	62.0	2×10^{-5}
Neochrome Tank	81	0.03	87.0	.002
Breaks	-	0.67	70.0	8×10^{-4}
Total		7.99		0.290

Table 21

Calculation of L_{eq} using Work Study Data

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